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SKILLS. EFFECTIVENESS OF PRACTICE METHODS
ON SIMULATED SPACE FLIGHT SKILL RETENTION

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DEGRADATION OF LEARNED SKILLS

Effectiveness of Practice Methods on Simulated Space Flight Skill Retention

by
Thomas E. Sitterley
and
Wayne A. Berge

July 1972

Prepared under Contract No. NAS9-10962 by

The Boeing Company
Seattle, Washington



for
Manned Spacecraft Center
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

Manual flight control and emergency procedure task skill degradation was evaluated after time intervals of from 1 to 6 months. The tasks were associated with a simulated launch through orbit insertion flight phase of a space vehicle. The results showed that acceptable flight control performance was retained for 2 months, rapidly deteriorating thereafter by a factor of 1.7 to 3.1 depending on the performance measure used. Procedural task performance showed unacceptable degradation after only 1 month, and exceeded an order of magnitude after 4 months. The effectiveness of static rehearsal (checklists and briefings) and dynamic warmup (simulator practice) retraining methods were compared for the two tasks. In general, static rehearsal effectively countered procedural skill degradation while some combination of dynamic warmup appeared necessary for flight control skill retention. Further, it was apparent that these differences between methods were not solely a function of task type or retraining method, but were a function of the performance measures used for each task.

FOREWORD

This report summarizes an experimental study accomplished as the second part of a program designed to investigate the degradation of learned skills as applicable to spaceflight tasks. The research reported here was begun in July 1970 and was completed in May 1971 for the NASA Manned Spacecraft Center under Contract NAS9-10962. The study was initiated by Mr. Earl LaFevers of the Crew Systems Division as NASA Project Monitor, and was then transferred to Dr. William E. Fedderson, Chief of the Behavioral Laboratory, Biomedical Laboratories Division, who was Project Monitor to completion.

The Boeing Program Manager was Dr. George D. Greer, Jr. and the Principal Investigator was Dr. Thomas E. Sitterley. The authors gratefully acknowledge the extensive assistance of Mr. Gale M. Rhoades who provided simulator modification, operation, experimental testing, and data reduction throughout the course of this study.

The first part of this investigation of degradation of learned skills was covered in Report D180-15080-1, Degradation of Learned Skills - A Review and Annotated Bibliography.

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1. INTRODUCTION

The success and safety of any flight mission is dependent upon not only the design and mechanical integrity of the flight vehicle, but also to a very great extent upon the capability and preparedness of the pilot. With the advent of manned space flight, the demands placed upon the astronaut's ability to perform his tasks have been extraordinary. The demands on the abilities of astronauts to provide manual control intervention in both normal and emergency modes of operation has paralleled the significant increases in mission complexity and duration. During this period of ever increasing mission complexity, the opportunity for equipment failure has likewise increased dramatically. The success of many missions and more than once the lives of the crew were saved only through the astronauts' skills and thorough training.

Current Apollo flight crew training for lunar landing missions is illustrative of the type of training necessary to ensure mission success. After being selected, the astronaut groups spend approximately 18 months in a general flight training program which includes detailed system briefing on all spacecraft systems, environmental familiarization and survival training. After completing the 18 month training program, the crew member is ready for assignment to a flight mission or to specific mission training. In the case of the lunar landing mission this training adds up to a total of approximately 2200 hours, scheduled over a 44 week period (Slayton 1967). The integration and scheduling of this training must be carefully planned because of the vast number of tasks to be learned over the multi-year training program. Throughout the program, previously learned mission elements must be systematically reviewed in order that the skills are not forgotten at the completion of training. During the course of mission training, literally hundreds of hours are spent in practicing the required mission skills on highly sophisticated, high fidelity spacecraft simulators.

In this and future decades, spacecraft with even longer, more complex flights will be developed. Many will be a significant departure from

previous missions, having greater autonomy from ground based control, and with flight control tasks far more complex than ever before. Space stations with missions of one year or more, and manned interplanetary flights with missions of two years and longer will be possible. The greater complexity and duration of these future space explorations will make astronaut performance all the more critical to overall mission success and safety.

Past experience indicates that the probability of catastrophic failure is increased substantially if high performance in skill retention is not effectively maintained over long durations of task inactivity. However, the benefits of months of continuous training on the ground and in simulators will no longer be available to the astronauts on these long duration missions. A system of onboard refresher training will be required to maintain the critical flight, procedural, and operational skills of the astronauts.

The configuration of this training system could involve a broad range of subelement complexities depending on the nature and type of astronaut tasks, the time since last task performance, and the degree of original training, or overtraining. The least complex subelement might be nothing more than a review of verbal and pictorial briefing aids similar to those found in current checklist and flight operations manuals. A middle level of complexity could involve the use of simulation software within the spacecraft computers to operate onboard equipment in a training mode. Beyond this may be the application of more sophisticated combinations of software, computers, and simulation/training hardware to provide high fidelity reproduction of spacecraft system dynamics and the operational visual environment associated with critical mission operations, phases, and maneuvers.

The impact of providing onboard training dictates that training requirements be carefully assessed so that efficient, cost effective systems can be designed. Each increase in the level of onboard training system complexity will be accompanied by a corresponding increase in the demands placed upon the limited volumetric space, weight and electrical

power capacities of the spacecraft. The system must provide, therefore, only the specific type, extent, and fidelity of training that will satisfy the goals of mission safety, reliability, and success. System design which is more elaborate or complex than required to satisfy these goals without compromise is not only wasteful of resources, but may also compromise the potential range of mission objectives.

A serious problem facing systems designers, then, is the precise specification of the astronaut tasks and skills which are subject to degradation, the interval of time since last practice which will result in significant degradation, and the identification of those parameters which can be expected to reduce or modify the nature of performance degradation. Recognition that the forgetting of learned skills can produce major consequences affecting overall successful performance is not new. Both the human performance literature and personal experience confirm that forgetting is basic to human behavior.

The problem of skill retention is complex, however, and the review of both operationally oriented and classical experimental literature on skill retention reveals a variety of conflicting data. Skill retention can be affected by a great number of independent variables and conditions. Fortunately over sixty years of literature concerned with the long term retention of skill performance was reviewed by Naylor and Briggs (1961) who provided both important conclusions and general organization for variables which had been examined. Using their reviews as a background against which the more recent literature could be compared and assessed, Gardlin and Sitterley (1972) provided an overview of the more recent literature which could be related to piloting and space flight tasks. Four basic categories or parameters which affect skill retention have been highlighted in the literature: a) task environment and task type or organization, b) amount and type of original training, c) the length of the retention interval, and d) the type of interim practice.

Three general types of tasks have been highlighted in the classical literature: verbal (cognitive), discrete psychomotor and continuous psychomotor. In evaluating the relationship between tasks characterized

as continuous (tracking) and discrete or sequential (procedural tasks), Naylor and Briggs (1961) indicated that continuous tasks are retained best. They pointed out that this finding was somewhat superficial, however, since the primary difference between tasks requiring discrete and continuous responses was largely a question of organization. Typically the procedural task has less spatial or temporal organization than does the tracking task. While useful from the standpoint of task description, the procedural task/continuous control task dichotomization in the literature can lead to incorrect prediction of the retention of flight skills. Piloting an aircraft, while primarily psychomotor in nature, requires a significant cognitive contribution in terms of information integration and decision making. The cognitive, discrete, and continuous control task elements are often represented to varying degrees in the flight control task. The effects of these elements on total task performance must be defined, with the prediction of skill retention closely tied to the defined measures of task performance.

Even the most straightforward generalizations such as "the higher the initial level of performance at the end of training the lower the performance degradation" or "the longer the period between training and subsequent performance the greater the performance degradation" are not consistently supported. Much of the conflict in the literature apparently occurs because many studies, directed toward the same question, use widely divergent tasks, performance criteria, and subject populations. Particularly critical here are the task characteristics and specification of performance criteria; however, when care is used in defining the type of task an apparent superiority in skill retention is found for continuous control tasks as opposed to procedural tasks. Likewise, within a task type both final training acquisition performance and initial retention performance vary positively with the amount of training.

The duration of the retention interval has considerable validity as an influential variable: the longer the retention interval the greater the skill loss. However, the amount of skill degradation appears to be highly task specific. While continuous control tasks appear to be retained best, very few studies have systematically evaluated skill retention

for both procedural and continuous control tasks over a broad range of skill retention intervals while keeping task conditions constant. Generally, the effects of task rehearsal or warmup practice mitigate the skill loss usually associated with a no practice interval of time. The importance of practice has been shown to be greater for retention intervals of longer durations. Further, the relative benefits of the same amount of practice are greater for procedural tasks as compared to continuous control tasks. There are, however, conflicts in the literature which appear to stem from the fact that insufficient data have been systematically collected to evaluate the type of practice most suitable for procedural and continuous control tasks over a sufficiently wide range of retention intervals.

Purpose

Both operational experience and the experimental literature, its inconsistencies notwithstanding, indicate that skill retention in future complex and long duration space missions will be a problem. It is also known that retraining techniques can be effective in countering the effects of time and interference on skill degradation; however, neither experience nor the literature specify, other than in a very general fashion, the time based quantitative degradation of spaceflight skills or the specific rehearsal or warmup techniques that will effectively counter that degradation in a consistent and systematic fashion.

Using a spacecraft simulator and relatively operationally oriented tasks, the purpose of this study was: a) to determine whether skill degradation of the simulated tasks was indeed significant and what interval of time without rehearsal or warmup was critical for skill retention; b) to investigate the effectiveness of static rehearsal and dynamic warmup for procedural and continuous control tasks; and c) to determine the relationship between performance criteria and the type of practice best suited for the tasks.

2. METHOD

A series of tests using a total of 45 subjects was conducted to measure skill retention on continuous control and procedural tasks. The primary task involved manual control of a reusable space vehicle during the boost phase. Time intervals were covered ranging from 1 to 6 months, and conditions investigated included: no practice, immediate rehearsal, distributed rehearsal, warmup and combinations of immediate and distributed rehearsal with warmup. Rehearsal involved the use of visual briefing materials, oral review and written testing prior to the simulated booster flight. Warmup involved repeating the actual flight in the test simulator. Table 1 summarizes the test conditions and time intervals investigated.

Table 1: Retention Practice Conditions by Subject Group

SUBJECT GROUP	RETENTION PRACTICE CONDITIONS	TIME INTERVAL
1	NO-PRACTICE	1 MO
	IMMEDIATE WARMUP	1 MO
	DISTRIBUTED WARMUP	3 MOS
2	NO-PRACTICE	2 MOS
	IMMEDIATE WARMUP	2 MOS
3	NO-PRACTICE	3 MOS
	IMMEDIATE WARMUP	3 MOS
4	NO-PRACTICE	4 MOS
	IMMEDIATE WARMUP	4 MOS
5	NO-PRACTICE	6 MOS
	IMMEDIATE WARMUP	6 MOS
6R	IMMEDIATE REHEARSAL	3 MOS
	REHEARSAL + WARMUP	3 MOS
7R	DISTRIBUTED REHEARSAL	3 MOS
	DISTRIBUTED REHEARSAL + WARMUP	3 MOS
8R	IMMEDIATE REHEARSAL	6 MOS
	REHEARSAL + WARMUP	6 MOS
9R	DISTRIBUTED REHEARSAL	6 MOS
	DISTRIBUTED REHEARSAL + WARMUP	6 MOS

The subjects were randomly assigned to one of 9 test groups (5 subjects to a group). They were then systematically trained until they performed at a level equivalent to a specified qualification criteria. Depending upon

the group assignment, the subjects were scheduled for testing, or rehearsal and eventual testing, at the specified intervals. Performance data were collected and compared to the qualification data to determine the degree of skill retention and the effects of the various skill retention practice methods.

Subjects

For this investigation it was determined that relatively naive subjects could provide the required data more cost effectively than highly trained test pilot subjects. Previous investigations at Boeing have indicated that non-pilot subjects can be trained to perform specific space vehicle control tasks at a level of performance comparable to trained pilots, if the subjects did not approach task load limits, and if adequate part-task training was provided. The subjects required about 5 times as much training as pilots on the same control task, but to train and test 45 skilled astronauts or operational pilots and limit their exposure to space flight and aircraft flight training tasks for periods of 1 to 6 months was an operationally impossible situation even if cost was not considered.

The subject population met the following requirements:

1. College degree
2. Age under 50
3. Vision 20/20 corrected
4. Commitment to no flight activities during the test period

The test subjects were selected from a voluntary population of available Boeing personnel. All subjects were engineers or scientists within the engineering or technical staffs. Professional backgrounds were varied, ranging from aerodynamic performance and control system engineers to research scientists. Forty-five subjects were required for the experiment. Five additional subjects did not complete training for either scheduling or vision reasons.

Test subject ages ranged from 23 to 50 with a mean of 35. The age standard deviation was 5.6 years. Of the 45-man group, 21 subjects

had 20/20 vision uncorrected and 21 subjects had 20/20 vision corrected. Three subjects had less than 20/20 vision: 1-20/40 corrected; 1-20/30 corrected; 1-20/25 uncorrected. An examination of their data revealed no significant differences from the remaining members of their groups.

Thirty-five of the 45 tested subjects had no previous flight control experience. Eight out of the remaining ten subjects had less than 140 hours in light aircraft and none of these eight had flown since 1968. Two out of the ten experienced subjects had significant military flight control experience during the Korean War and earlier. One subject had 3700 hours in military transport reciprocating engine aircraft. The other experienced subject had 1600 hours primarily in light observation aircraft and 3200 hours in rotary wing aircraft. None of the test subjects controlled an aircraft during the duration of the test.

Task Description

The primary task involved manual control of a reusable spaceflight vehicle during the phase from lift-off to orbit insertion. Subject performance was measured on two subtasks: a continuous control task, and a procedure task. Continuous control data were taken independently of the procedure task data. Procedure task data were taken while the subjects were performing the continuous control task; however, the procedure task was designed to isolate continuous control task loading effects from the procedure task data.

Continuous Control Task

The continuous control task required the subject to manually control a stabilized space vehicle from launch to orbit. A summary of the vehicle characteristics and orbit insertion parameters is presented in Table 2. The subject was required to scan displays, compare the displayed data in a time reference with the trajectory guidance card, and provide control inputs to fly the optimum trajectory. The total ascent profile required 6 minutes, 44 seconds to complete.

Table 2: Summary of Simulation Vehicle and Orbit Insertion Characteristics

BOOSTER		
STAGE WEIGHT		2,722,000 LB
USEFUL PROPELLANT		2,220,000 LB
VACUUM THRUST (TOTAL)		4,840,000 LB
SPECIFIC IMPULSE (VAC)		440.4 SEC
ORBITER		
IGNITION WEIGHT		778,000 LB
PROPELLANT CONSUMED TO INJECTION		516,936 LB
VACUUM THRUST		1,392,600 LB
SPECIFIC IMPULSE (VAC)		464.9 SEC
INSERTION CONDITIONS		
TIME		404 SEC
VELOCITY (RELATIVE)		25,029 FPS
ALTITUDE		273,000 FT
FLIGHT PATH ANGLE		.32°
INCLINATION		54.8°
RANGE FROM LAUNCH SITE		592 N MI

The display panel appears in Figure 1. Displayed information includes mission time, altitude, altitude rate, altitude error, angle of attack, velocity, vehicle pitch and roll error, side slip, and compass heading error. The vehicle pitch and roll error were displayed on an early model Attitude Director Indicator (ADI). This ADI was installed in several models of the Boeing 707 commercial jet aircraft. The altitude error was displayed on a CRT. Remaining information was displayed on vertical or horizontal scale electromechanical instruments. The recommended procedure for flying the boost profile is described in the training data package (rehearsal information package) contained in the Appendix.

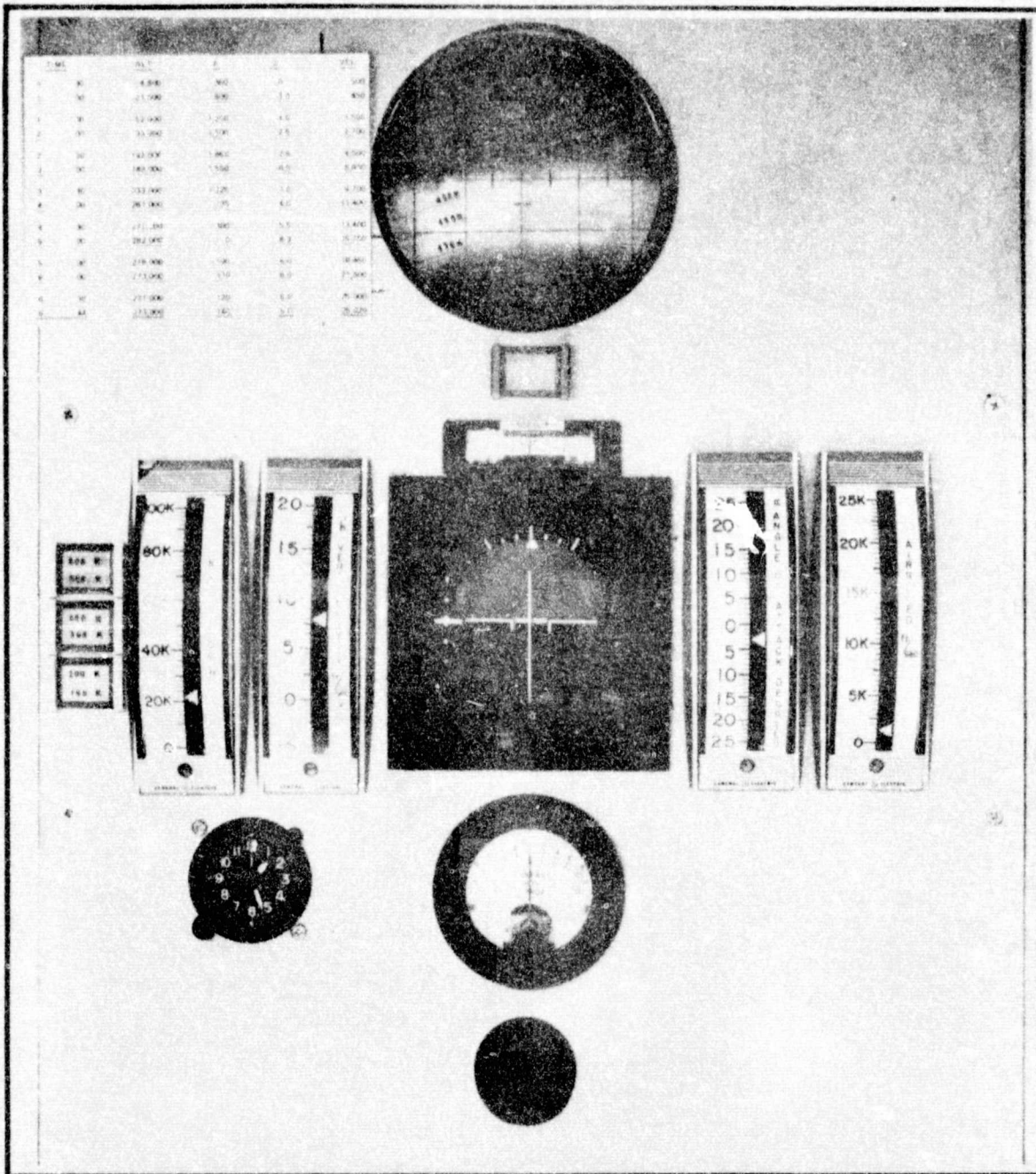


Figure 1: Cockpit Display Panel for Flight Control Instruments

The following parameters were recorded for analysis of subject performance: altitude error and altitude rate error at orbit insertion; total integrated pitch error and total integrated altitude error. The following definitions apply:

Altitude error - The error in feet from the desired altitude of 271,000 feet at orbit insertion (the end of the manually controlled boost phase).

Altitude rate error - The error in feet per second from the desired altitude rate of change of +140 ft/sec at orbit insertion.

Total integrated pitch error - The absolute pitch error from the nominal pitch profile integrated over the duration of the total manually controlled flight, measured in degree-seconds.

Total integrated altitude error - The absolute altitude error from the nominal altitude profile integrated over the duration of the total manually controlled flight, measured in foot-seconds.

Procedure Task

An "emergency" occurring in the Attitude Indicator System formed the basis for the procedure task. The task required the subject to respond to a failure indication and make a series of decisions based on sequentially requested information displayed on a meter. The procedural task display and control panel, shown in Figure 2, was located in the upper left quadrant of the cockpit.

The subject was required to start the procedural task while he was actively engaged in the continuous control task (manual control of the vehicle ascent trajectory). Within the first 2 minutes of the ascent, an "Attitude Indicator Failure" light was illuminated by the procedure task operator (experimenter). The subject responded by actuating the "Auto Control" pushbutton which put the simulator on automatic control and relieved the operator from the control task. This effectively separated the two tasks and eliminated experimental data interference. The

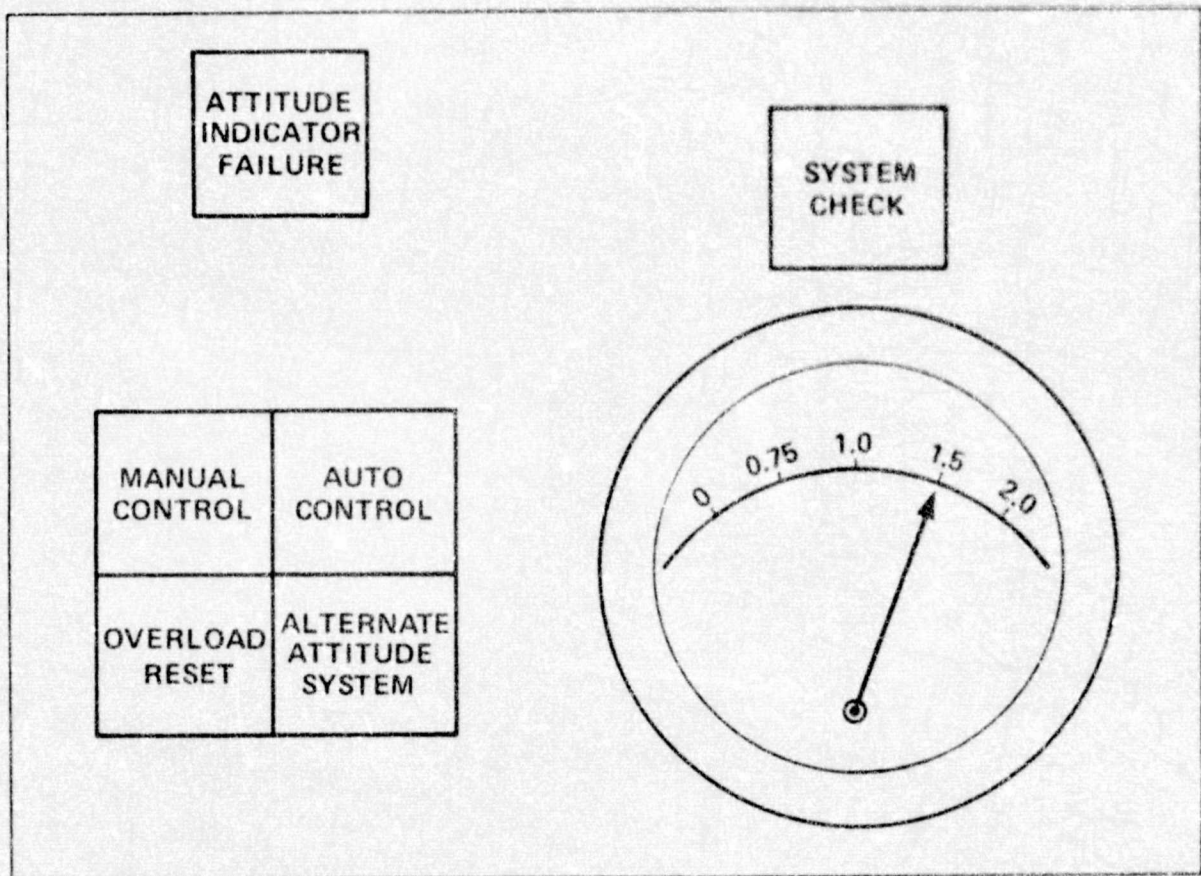
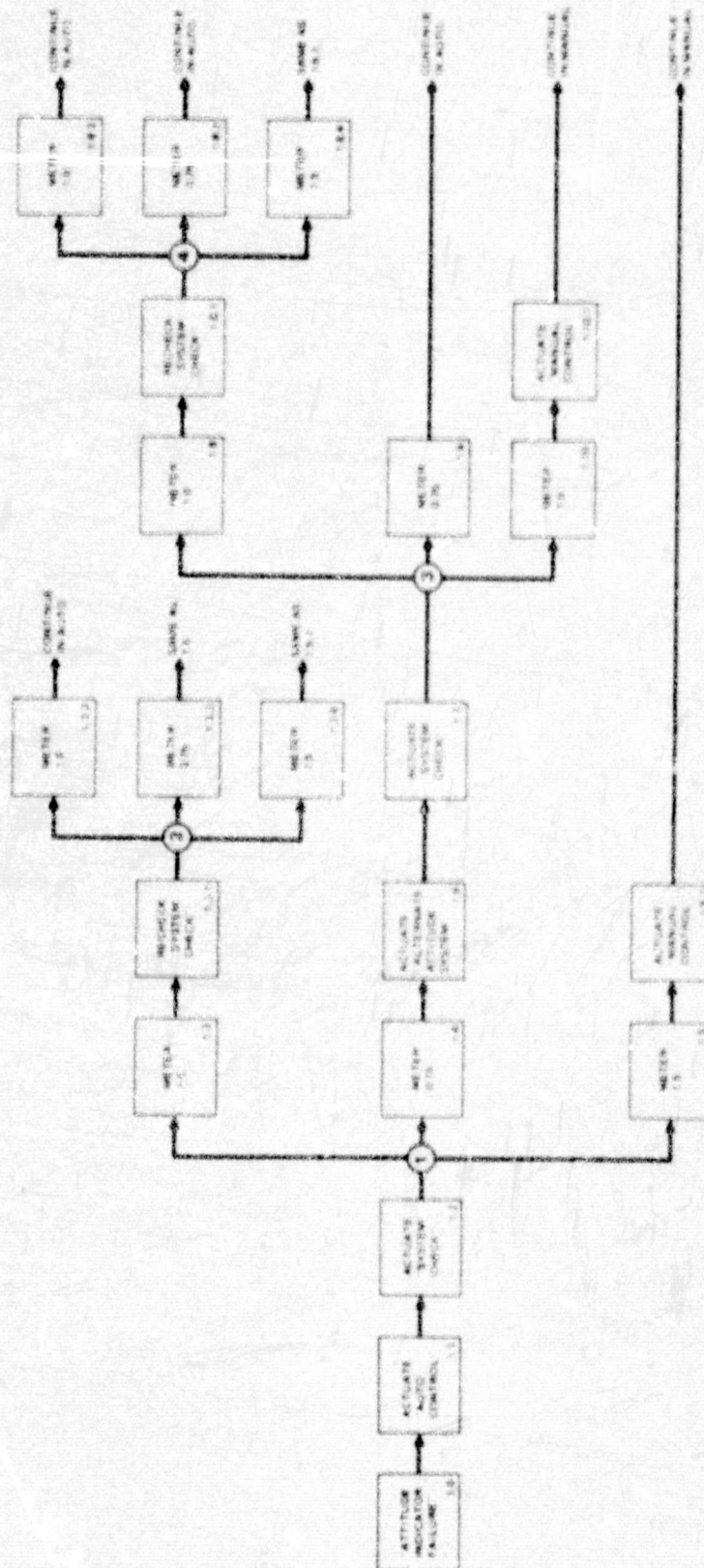


Figure 2: Procedural Task Display/Control Panel

subject next actuated the "Attitude System Check" pushbutton which caused a meter to read one of three numbers: 0.75, 1.0, or 1.5. Based upon the meter reading, the subject had to decide which of three control sequences to follow as indicated in the logic diagram (Figure 3).

The three indications were: system O. K. (1.5), system failure (0.75), or meter reading is inconclusive (1.0). If the system was O. K. (1.5), the subject actuated "Manual Control" and continued manually controlled flight. If a failure was indicated (0.75), the subject actuated the "Attitude Alternate" control and was required to run another system check. At this point another meter indication was programmed which led to continuing the flight in auto or returning the system to manual control. If the meter reading was inconclusive (1.0), the subject was required to recheck before proceeding into another control sequence branch of the logic diagram. Whenever the subject took an action that was out of



NOTE: IF OUT OF SEQUENCE ACTION IS TAKEN, ACTIVATE CONTROL AND RESET AND REINITIALIZE SEQUENCE

Figure 3: Procedure Task Logic Flow Diagram

the programmed sequence, an "Overload Indicator" came on and had to be actuated before restarting the proper sequence.

Performance data was automatically recorded for the following parameters: initial response time, decision time, sequence time, total time; decision, sequence and total errors. The following definitions apply:

Initial Response Time -	Time measured from initiation of test to actuation of Auto Control Button (first subject action).
Decision Time -	Time measured from initiation of System Check button to actuation of next appropriate button (measures time to read meter, decide and take appropriate action).
Sequence Time -	Time measured between sequential button actuations: Auto Control to System Check and Alternate Attitude Systems to System Check.
Total Time -	Time measured from initiation of test until actuation of last button in the test sequence.
Decision Error -	Actuation of the wrong button following actuation of the System Check button (meter reading).
Sequence Error -	Actuation of any out of sequence button with the exception of decision errors.
Total Errors -	Summation of decision and sequence errors.

Equipment

The experimental test was conducted in the Boeing Human Performance Multistress Laboratory located in Kent, Washington. The facility is normally used to evaluate crew performance under individual or combined environmental stresses which may include vibration, temperature, pressure, humidity, noise, and various atmospheric gas compositions. The Multistress Laboratory is connected to a visual display generating facility and a major computing system in which six large general purpose

analog computers and two general purpose digital computers are combined with a full complement of supporting input/output display and recording equipment.

The simulation laboratory is depicted in Figure 4. The laboratory is composed of computer interface equipment, display/control and task programming equipment, test operation and experimenter's control consoles, and a subject test chamber. The test chamber, designed for environmental stress testing, provides a 100 cu ft cockpit area. The pilot's chair is mounted on the chamber door which is rolled closed on rails. Figure 5 depicts the entrance to the test chamber with a subject prior to a test run. The three-axis side arm controller was mounted on the right arm of the pilot's seat. The cockpit displays and remaining controls were mounted on the end bulkhead of the test chamber (Figure 6).

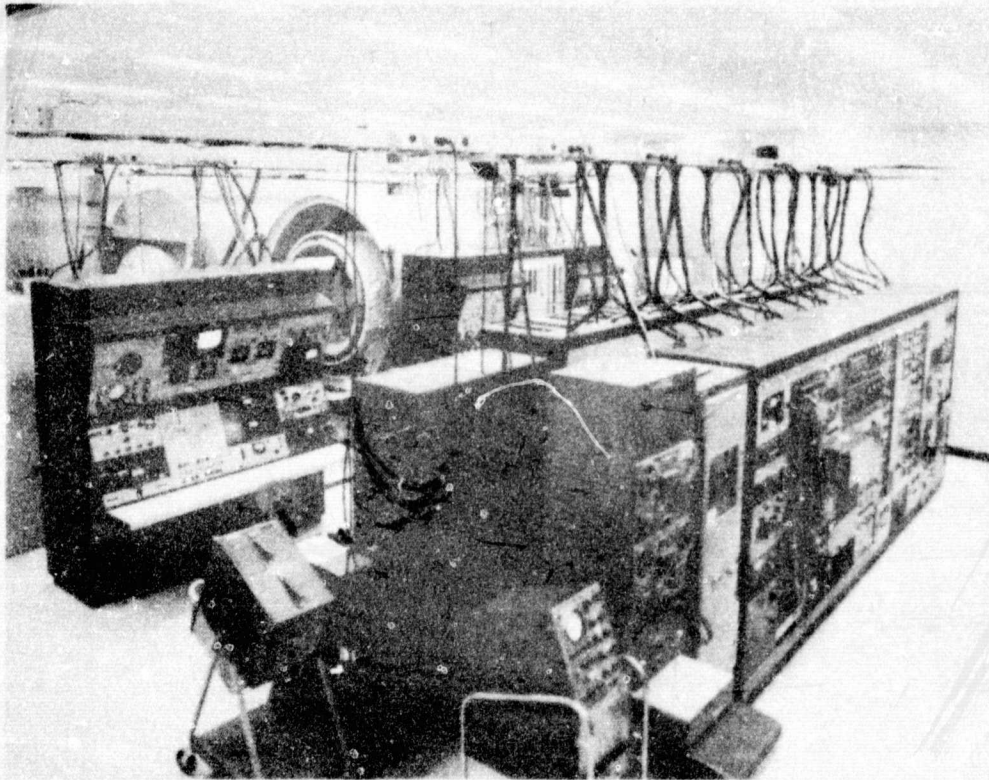


Figure 4: Simulation Laboratory

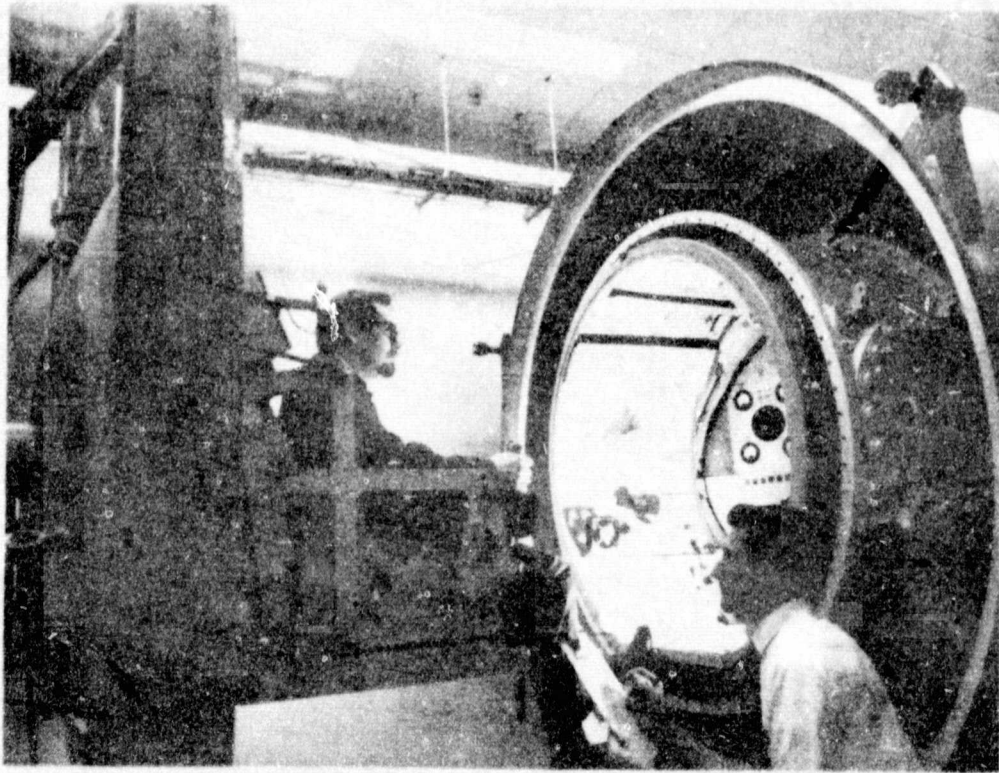


Figure 5: Test Chamber Entrance with Seated Subject Prior to Test Run

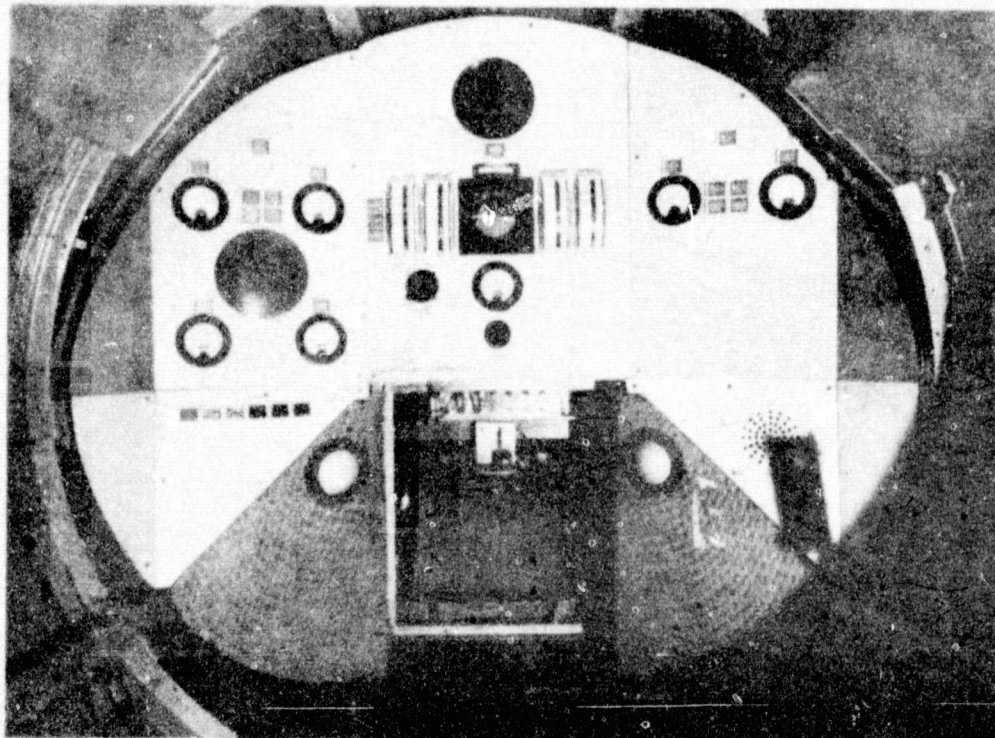


Figure 6: Test Chamber Interior

Continuous Control Task

The dynamic flight characteristics of the simulated reusable space vehicle were derived from early Boeing Space Shuttle studies. Two analog computers were used to simulate the flight characteristics using a point-mass simulation model. During the training of the first 22 subjects, a Beckman EASE 2100 analog computer provided dynamic flight characteristics and the required data collection functions. Because of better availability and improved operational arrangements, the EASE 2100 simulation was transferred to the Applied Dynamics 256 solid state analog computer. The AD 256 was used for the remainder of the experiment, and the EASE 2100 was kept available as a backup computer.

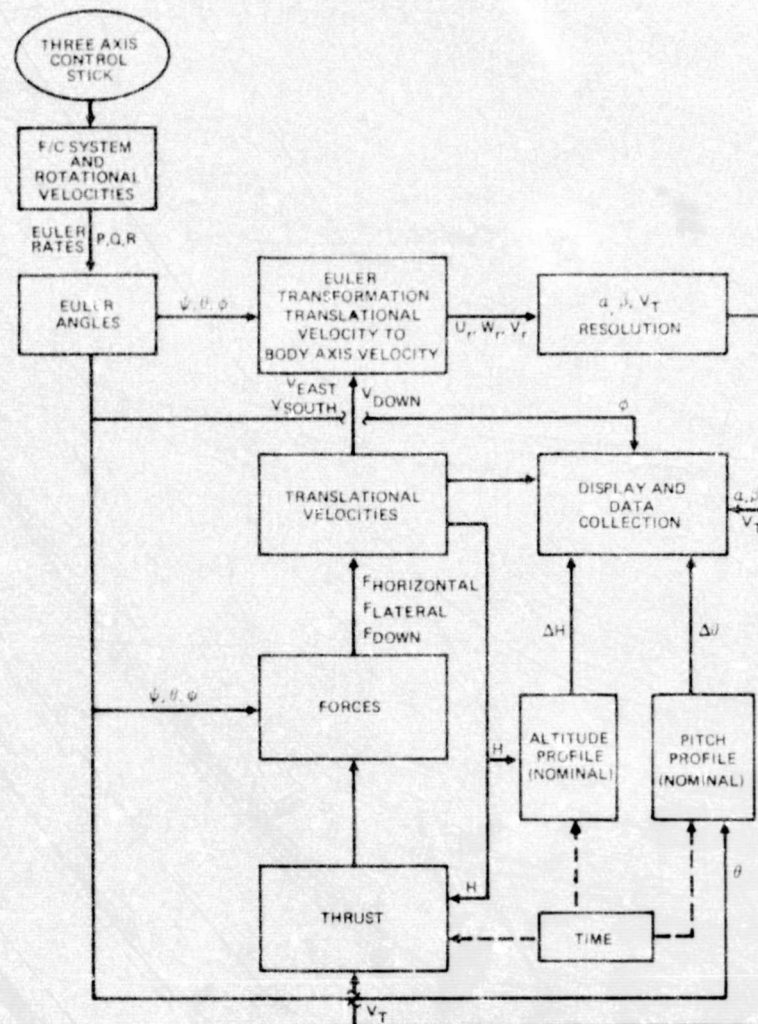


Figure 7: Schematic of Flight Simulator Model

A summary flow diagram of the flight simulation model appears in Figure 7. Stick inputs to the stability augmented flight control system developed Euler rates (rotational velocities about the vehicle axes). The Euler rates were then integrated to produce Euler angles. Using the Euler transformation process, the Euler angles were combined with translational velocities and transformed into body axis velocities (U_r , W_r , V_r) which were resolved into angle of attack (α), and angle of slideslip (β), and total velocity (V_T). All velocities were relative to the point of launch. Alpha and Beta were displayed and monitored in the data recording system. Thrust was generated as a function of time and altitude was automatically terminated when total velocity was optimum. In the next operation, thrust, gravity and centrifugal forces were resolved into horizontal, lateral and downward components. The force components were then converted into velocity components which were displayed and monitored for data. The velocity components were also fed into the Euler transformation process. Altitude rate was integrated and an altitude signal returned to the thrust function generator.

The control stick was a 3-axis, sidearm controller developed from an Air Force design originally evaluated for use in the Aerospace Astronaut Training Program at Edwards AFB. The stick provided "rate" inputs as a linear function of angular displacement and stick force. Stick sensitivity data appears in Table 3.

Table 3: Three Axis Control Stick Characteristics

	RANGE	SENSITIVITY	REPONSE CHARACERISTIC	FORCE	LOCATION AND TYPE
CONTROLLER PITCH	10.5°	0.332°/S/°	LINEAR	1.5 3 LB	SIDE ARM
CONTROLLER ROLL	12°	0.0415°/S/°	LINEAR	1.5 3 LB	SIDE ARM
CONTROLLER YAW	21°	0.420°/S/°	LINEAR	2 5 LB	SIDE ARM

The flight instrumentation is shown in Figure 1. A description of each instrument and the recommended flight control procedures appear in the Appendix. Display readability and sensitivity parameters appear in Table 4.

Table 4: Flight Instrument Sensitivity and Readability Parameters

CONTROL/INDICATOR	RANGE	SENSITIVITY	DIVISIONS	FACE SIZE	TYPE
ALTITUDE, H	0 - 100 K	2,000'/DIV	50	4½ x 1½	VERTICAL
ALTITUDE RATE, \dot{H}	-5 - + 20 x 100	50'/SEC/DIV	50	4½ x 1½	VERTICAL
ANGLE OF ATTACK, α	25° - 0 - 25°	1°/DIV	50	4½ x 1½	VERTICAL
AIR SPEED	0 - 25 K	500'/SEC/DIV	50	4½ x 1½	VERTICAL
SIDE SLIP	±15°	1°/DIV	30	2½" x ½	HORIZONTAL
COMPASS HEADING	±10°	0.4°/DIV	50	2¼" DIAM	STANDARD
HDI PITCH ERROR	±2.15°		4	3-5/8" DIAM	STANDARD
HDI ROLL ERROR	360°		6	3-5/8" DIAM	STANDARD
ALTITUDE ERROR, ΔH	±8,000'	4,000'/DIV	4	5½" DIAM	STANDARD
CLOCK	8 DAY	1"/DIV	60	2" DIAM	STANDARD

Procedure Task

The Procedure Task Function Logic System (PTFLS) formed the basis of the procedure task equipment. This equipment was composed primarily of logic gate and flip flop circuits designed to drive the procedure task displays and measure operator sequential response and response time performance. The Attitude Indicator System failure operation was programmed to operate according to the procedure task logic. The task displays and controls were mounted on the upper left quadrant of the cockpit instrument panel.

The PTFLS data were recorded as analog signals on FM magnetic tape. The PTFLS also operated a digital clock readout display on the experimenter's control panel which indicated total task response time for

immediate evaluation by the test operator. A hybrid computer program for an XDS 9300 digital computer and an EASE 2100 analog computer, was used to convert the data from FM magnetic tape to digital magnetic tape and to provide data analysis and reduction. The EASE was scaled to sense signal level changes, converting the signals to interrupt functions which were fed directly to the XDS 9300 digital computer. This computer processed the digital interrupt signals in conjunction with a program that produced a compilation of addressed data files suitable for analytical processing. The 9300 stored the addressed data files on magnetic tape which then were processed through one of six analysis subroutines to obtain the desired performance data.

Test Operator Station

The test operator's station included the continuous control task and procedure task control panels, a Frieden Flexowriter, an X-Y plotter, a remote control panel for an Ampex FR 100/1300 tape recorder and an electronic calculator. The flexowriter, X-Y plotter and the calculator supported data collection and preliminary analysis of the continuous control task data. The Ampex tape recorder was used to record procedure task FM signal data.

Subject Training

Continuous Control Training

The subject training procedure was standardized. Each subject received a basic lecture corresponding to the training data package that is contained in the Appendix. This data package also served as the rehearsal information package. Following the lecture, the subject was seated in the cockpit and familiarized with the operational instruments, indicators and flight initiation procedures. Each instrument and its scale factor was reviewed with the subject.

The subject was then instructed to observe the instruments while the simulator flew 2 automatic runs at 10 times real time. This familiarized the subject with the working characteristics of the displays and demonstrated the ranges displayed on each instrument. The subject then

observed a real time automatic run and was instructed on the desired instrument scan pattern and encouraged to check the automatically flown profile against the flight profile card. At this time the subject started his first manually controlled flight. The instructor observed and "talked" the subject through the first three training flights. The subject continued to fly in sets of 5 flights until his average performance for 5 consecutive flights met the following training qualification test performance criteria:

$\frac{\text{Altitude}}{\text{Mean} \pm}$	1500'	Standard Deviation: 2000 ft
$\frac{\text{Altitude Rate}}{\text{Mean} \pm}$	50 ft/sec	Standard Deviation: 60 ft/sec
$\frac{\text{Integrated } \Delta \text{ Alt.}}{\text{Total} <}$	700,000 ft/sec	
$\frac{\text{Integrated } \Delta \text{ Pitch}}{\text{Total} <}$	465 deg-sec	

Procedure Training

The standard training procedure in this task was to give the subject a lecture on the procedure task using the material in the Appendix. Next, the subject was seated in the cockpit and the procedure was demonstrated using the actual input controls and displays. The subject was then presented with 5 sets of the 14 different procedures in random sequence, and 2 sets of 5 specific procedures in a specified sequence. Table 5 illustrates the meter readings at each decision point for the 14 procedure combinations used in training. The five test procedures are also indicated with their test sequence. During the training period the subject was permitted to refer to the procedural flow diagram (Figure 3).

At the next session, the subject received training in the same manner. If the subject's total time for each procedure stabilized (was not continuing downward significantly) at the end of the fifth set of procedures, the next 2 sets of the 5 specified procedures were given as a test. If the subject made an error during the last set of 5, the same set was repeated until no errors occurred since the qualification criteria was:

Table 5: Procedure Task Decision Point Sequences

PROCEDURE NUMBER	DECISION POINT METER READING				COMPUTER MODE AT COMPLETION
	1	2	3	4	
1 *4	1.5	NA	NA	NA	MANUAL
2 *5	0.75	NA	1.5	NA	MANUAL
3	1.0	1.0	NA	NA	AUTO
4 *1	1.0	0.75	1.0	1.5	MANUAL
5	1.0	0.75	1.0	1.0	AUTO
6	0	NA	NA	NA	AUTO
7 *3	1.0	0.75	1.0	0.75	AUTO
8 *2	0.75	NA	1.0	1.0	AUTO
9	1.0	1.5	NA	NA	MANUAL
10	0.75	NA	0.75	NA	AUTO
11	1.0	0.75	1.5	NA	MANUAL
12	0.75	NA	1.0	1.5	MANUAL
13	1.0	0.75	0.75	NA	AUTO
14	0.75	NA	1.0	0.75	AUTO

*SEQUENCE OF TEST PROCEDURES

1. Subject's total time per procedure must have stabilized.
2. No errors permitted in the test run (last 5 procedures).

If the subject's times had not stabilized at the end of the second session, additional sessions were conducted until the qualification criteria was achieved.

Thirty-seven of the 45 subjects qualified on the procedure task in two sessions. The remaining 8 subjects qualified in 3 sessions. Two of the 6-month test groups (Groups 5 and 8R, a total of 10 subjects) were qualified and tested in a no-flight mode; that is, they were not required to fly the continuous control task while performing the procedure task. This deviation was necessary with the first two groups because they had previously qualified on the continuous control task (before the procedure task was operational) in order to meet the 6 month interval contractual obligation. The continuous control task experiment would have been jeopardized if these groups had an opportunity to perform the continuous control task between the date of qualification and the date of testing.

Group Training Performance Equivalence

A total of eight months were required to complete the training of the nine groups of test subjects on both the continuous control and procedure tasks. The 45 subjects who completed training flew a total of 1,547 boost profiles for the continuous control task, averaging 34.4 flights to qualification (range: 13 to 68). For the procedure task, a total of 8,410 trials were completed by the test subjects for an average of 186.9 trials to qualification (range: 160 to 240).

These subjects were randomly assigned to the nine retention practice conditions and sequentially trained. Training commenced first with the subjects in the 6-month retention interval groups and progressed to the shorter interval groups. By the time 60 percent of the subjects had completed training, the first subjects in the long retention interval groups were ready for final testing. Because of the time required to train each subject on both tasks, and the number and duration of the retention intervals under examination, it was not possible to match each of the nine treatment groups on the basis of training qualification performance.

In order to determine the extent of any qualification performance differences between the treatment groups, and to assess the possible impact on the interpretation of the retention test results, a series of between group analyses were performed on the qualification performance data for both tasks. These analyses involved the application of the analysis of variance (ANOVA) statistic to the number of flights or trials to qualification and to each of the dependent performance measures for the two tasks. For the three significant differences found, the data were further evaluated using Duncan's New Multiple Range Test.

The number of training flights to qualification on the continuous control task was subjected to the ANOVA to determine if the groups differed significantly in terms of the amount of training received. No practical or significant differences across the nine groups was found. The analysis of the number of trials to qualification on the procedure task was likewise found to show no significant differences between the nine groups.

A total of eight ANOVA's were performed on the data and variance of the four continuous control dependent variables: altitude error and altitude rate error at cutoff, and integrated altitude and pitch error. Only the ANOVA's of integrated pitch error and altitude rate error variance revealed significant group differences. Table 6 depicts a summary of the significant analyses of the qualification performance.

It can be seen that, for both continuous control performance measures, the Duncan's test revealed overlapping sets of groups with no significant performance differences. For integrated pitch error, performance group 6R was significantly better than group 5 and groups 3 and 7R were significantly better than groups 8R, 2, 4, 9R and 5. All other combinations of groups fail to reveal significant differences. The results of the Duncan's test for altitude error variance indicated that group 6R was less variable than group 2, and group 7 less than groups 8R, 4, and 2.

Analysis of the procedure task qualification performance measures was limited to the four time measures: initial response time, decision time, sequence time and total response time. No analyses of errors were made because the qualification criteria required that no errors be committed during training qualification performance testing. The only significant group differences detected by the ANOVA were for initial response time. The summary of this result and the associated Duncan's test results are also included in Table 6. Once again a series of overlapping sets of groups with no significant performance differences were identified by Duncan's test. Specific group differences are summarized as follows: The performance of groups 4 and 3 was significantly faster than group 2; group 5 performance was faster than groups 1 and 2; and group 8R was faster than groups 6R, 9R, 7R, 1 and 2. All other combinations of groups did not reveal any performance differences in terms of initial response time.

Table 6: Training Qualification Test Performance--Summary of Significant Between Group Differences

DEPENDENT VARIABLE	ANALYSIS OF VARIANCE	DUNCAN'S TEST* (<0.05 BY GROUP NUMBER)
INTEGRATED PITCH ERROR (CONTINUOUS CONTROL)	<0.01 ($F = 3.380, 8$ AND 36 df)	3 · 7R · 6R · 1 · 8R · 2 · 4 · 9R · 5 _____
ALTITUDE RATE ERROR VARIANCE (CONTINUOUS CONTROL)	<0.05 ($F = 2.326, 8$ AND 36 df)	7R · 6R · 1 · 3 · 5 · 9R · 8R · 4 · 2 _____
INITIAL RESPONSE TIME (PROCEDURE TASK)	<0.01 ($F = 3.408, 8$ AND 36 df)	8R · 5 · 4 · 3 · 6R · 9R · 7R · 1 · 2 _____

*ANY TREATMENT GROUPS UNDERScoreD BY THE SAME LINE ARE NOT SIGNIFICANTLY DIFFERENT

The general conclusion to be obtained from the analysis of the subject's qualification data was that the nine treatment groups were very comparable in terms of their performance. Of the 17 measures of training equivalence for both tasks, only three showed any significant group differences. The widespread overlapping of sets of groups with no performance differences further reduced the overall impact of the three significant differences found. The relationship of the overlapping group sets to the experimental designs used to evaluate retention interval performance revealed that, to a very great extent, the group sets associated with a particular experimental design showed little or no performance differences.

Retention Interval Refresher Training

The 45 test subjects were divided into nine 5-subject groups to measure the effects of time on skill retention and to assess the effectiveness of two types of refresher training: static rehearsal practice and dynamic warmup practice. The group assignment to retention intervals and refresher training conditions are depicted in Table 7.

Table 7: Group Assignment to Retention Intervals and Refresher Training Conditions

SUBJECT GROUP	LENGTH OF NO-PRACTICE INTERVAL (MONTHS)					
	1	2	3	4	5	6
1	• TEST • WARMUP • TEST	• TEST • WARMUP • TEST	• TEST • WARMUP • TEST			
2		• TEST • WARMUP • TEST				
3			• TEST • WARMUP • TEST			
4				• TEST • WARMUP • TEST		
5						• TEST • WARMUP • TEST
6R			• REHEARSAL • TEST • WARMUP • TEST			
7R	REHEARSAL	REHEARSAL	• REHEARSAL • TEST • WARMUP • TEST			
8R						• REHEARSAL • TEST • WARMUP • TEST
9R	REHEARSAL	REHEARSAL	REHEARSAL	REHEARSAL	REHEARSAL	• REHEARSAL • TEST • WARMUP • TEST

The first five groups received no relevant practice during the retention interval. One of the five groups was tested one month after the completion of training, another group two months after training, another after three months, another after four months, and the last after six months, additional experimental data were obtained from the one-month group by retesting at the end of the second and third months. The first and second month retention tests thereby served as dynamic warm-up practice sessions for assessing the effects of monthly (distributed) dynamic warmup practice on skill retention over 3 months.

The remaining four groups were used to measure the effects of static rehearsal practice after time lapses of 3 and 6 months. Two of these groups received rehearsal practice after the 3 or 6 month retention

interval, followed immediately by retention testing. The other two groups received rehearsal practice every month during the retention interval and then once again at the end of the interval immediately prior to testing.

Each static rehearsal refresher training session was identical for all subjects in the rehearsal practice groups. The frequency of, and time at which this rehearsal training occurred, is depicted in Table 7. The rehearsal training consisted of: (a) a review of the flight training manual used during original training, (b) a series of fourteen 8 x 10 photographs of the cockpit environment, and (c) a written rehearsal test (Appendix). After the subjects arrived for their rehearsal briefing, they were read a standard introduction which reiterated the purpose of the study and what was expected of them. They were then provided a flight control manual for self review and the copies of the photographs of the displays. These photographs were black and white, 8 x 10 glossy prints sequentially depicting the continuous control task display panel as it appeared at each of the 13, 20-sec checkpoints and at orbit insertion as specified on the guidance reference card (Appendix, Figure A-3).

Upon completion of the flight manual review, the subject was instructed to review the photographs, paying particular attention to the coordination of the instrument readings at each checkpoint. In addition, the subject was instructed to try to anticipate the future flight progress as a function of the depicted instrument information. The next photograph in sequence provided the subject with feedback on the correctness of his predictions. After reviewing the flight control and procedure task briefing materials, the subjects were given a self-test in narrative form. These tests were designed to provide further reinforcement of key flight control and procedural operations and to assist the subjects in correcting misinterpretations of the tasks. The self-tests were jointly reviewed by the subject and the experimenter for correction and clarification.

Immediate Dynamic Warmup practice was provided to all subjects in all groups as a function of retention testing. The first task performance during the retention test, used to measure the effects of time and refresher training technique, was also used as the first of a series of additional continuous control flights and procedure sequences. The performance data taken after completion of this series of task operations was a measure of the effectiveness of immediate dynamic warmup practice on skill retention.

Performance Retention Testing

Pretest calibration checks of the simulator operation and flight dynamics were made prior to skill retention testing for each subject. Because the training and testing schedules overlapped, the simulator was virtually in continuous operation from the start of training to the end of testing, and routine recalibration checks showed no significant fluctuations in the simulator. As an additional measure, however, a series of real time and 10 times real time automatic flights were flown prior to the testing on each subject. Performance measures of these flights were compared with performance measures of automatic runs taken during that subject's training to ensure that the simulator was functioning the same for each subject. In addition, experimenter test pilots flew several flights prior to the subject's arrival in the simulator area to assess handling qualities and simulator characteristics. No significant changes in simulator operation were observed.

After the prescribed retention interval, each subject returned to the simulator area for skill retention testing. The subjects were told that their flight control and procedure task skill retention was going to be measured during the test session. If a subject was assigned to one of the static rehearsal refresher training groups, he received a complete rehearsal briefing prior to flight testing. The subject was then seated in the test chamber, the door was closed, and the intercommunications links between the subject and the experimenter were checked. The flight control guidance reference card, mounted on the instrument panel, served as a checklist for the flight control task, and the procedure task logic flow diagram was provided as a checklist for the procedure

task. The flow diagram was held in a folded condition by a clip to the test chamber bulkhead. The subject was instructed not to review the procedure task checklist until after the countdown was completed and the mission started. A special electrical circuit was installed on the bulkhead mounted clip to detect if the checklist was removed prior to the start of the flight. This system proved to be unnecessary as all subjects followed the instructions.

During the retention test session each subject flew the initial retention test flight followed by four more flight procedure sequences. Approximately one minute was required between each flight in the series of five to readout the performance data and reset the simulator. At the end of five flights, the subject was permitted to take a 5 minute break at which time he could get out of the test chamber and stretch his legs. After the rest period, the subject re-entered the chamber and continued to fly another series of five flights and procedure sequences.

3. RESULTS

The study data were analyzed as two separate evaluations for each of the two task types. The first, evaluated the effects of the duration of the no-practice retention intervals and the effects of dynamic warmup practice on skill retention. Data for this evaluation were obtained from the first 5-subject groups. The second, evaluated the effects of static rehearsal practice and dynamic warmup practice on skill retention at the 3- and 6-month retention intervals. The last four subject groups (6R, 7R, 8R and 9R) provided the rehearsal effects data, and the 3 and 6 months groups from the first evaluation provided the warm-up effects data.

Continuous Control Task

Effects of No-Practice Interval and Dynamic Warmup Practice

The effects of duration of the no-practice retention interval and the effects of dynamic warmup practice are depicted in Figures 8, 9, 10 and 11 for the flight control performance measures of altitude error, integrated altitude error, altitude rate error and integrated pitch error, respectively. The data plotted are the difference between the retention test and the qualification performance for each retention interval group. The qualification performance baseline was the performance achieved by each group at the end of training. The no-practice retention test data was obtained from the first flight at the end of the retention interval. The retention test with the benefit of one dynamic warmup practice was obtained from the second flight at the end of the retention interval, and the retention test with five warmup practices was obtained from the sixth flight at the end of the retention interval.

The data were analyzed using a two factor, analysis of variance design, with repeated measures (subjects nested within groups). Figure 12 depicts the analysis plan and ANOVA summary for the effects of no practice and dynamic warmup practice on skill retention. The results of these four ANOVA's and Duncan's Multiple Range Tests are

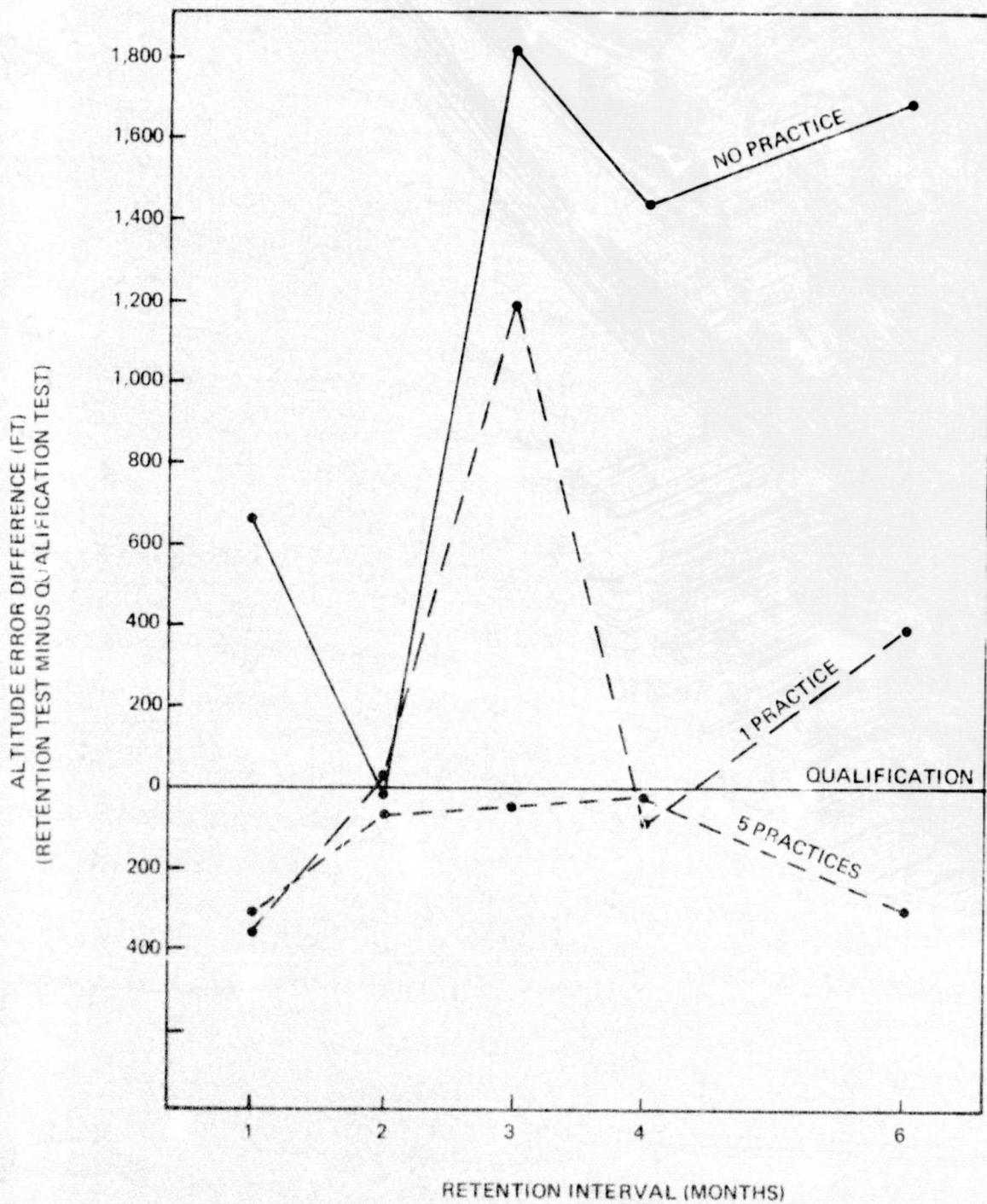


Figure 8: Altitude Error at Orbit Insertion--Effect of Retention Interval and Practice on Performance

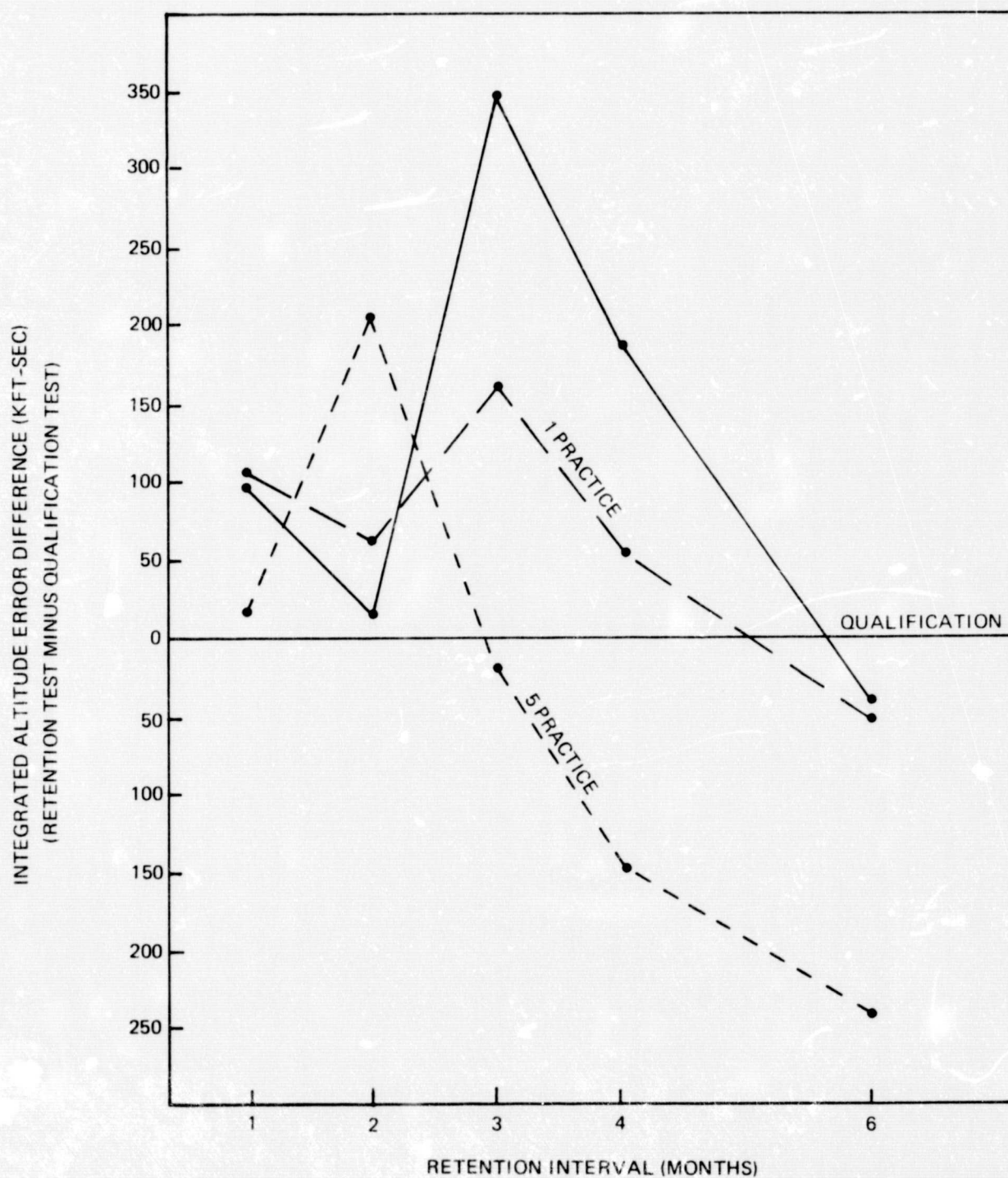


Figure 9: Integrated Altitude Error--Effect of Retention Interval and Practice on Performance

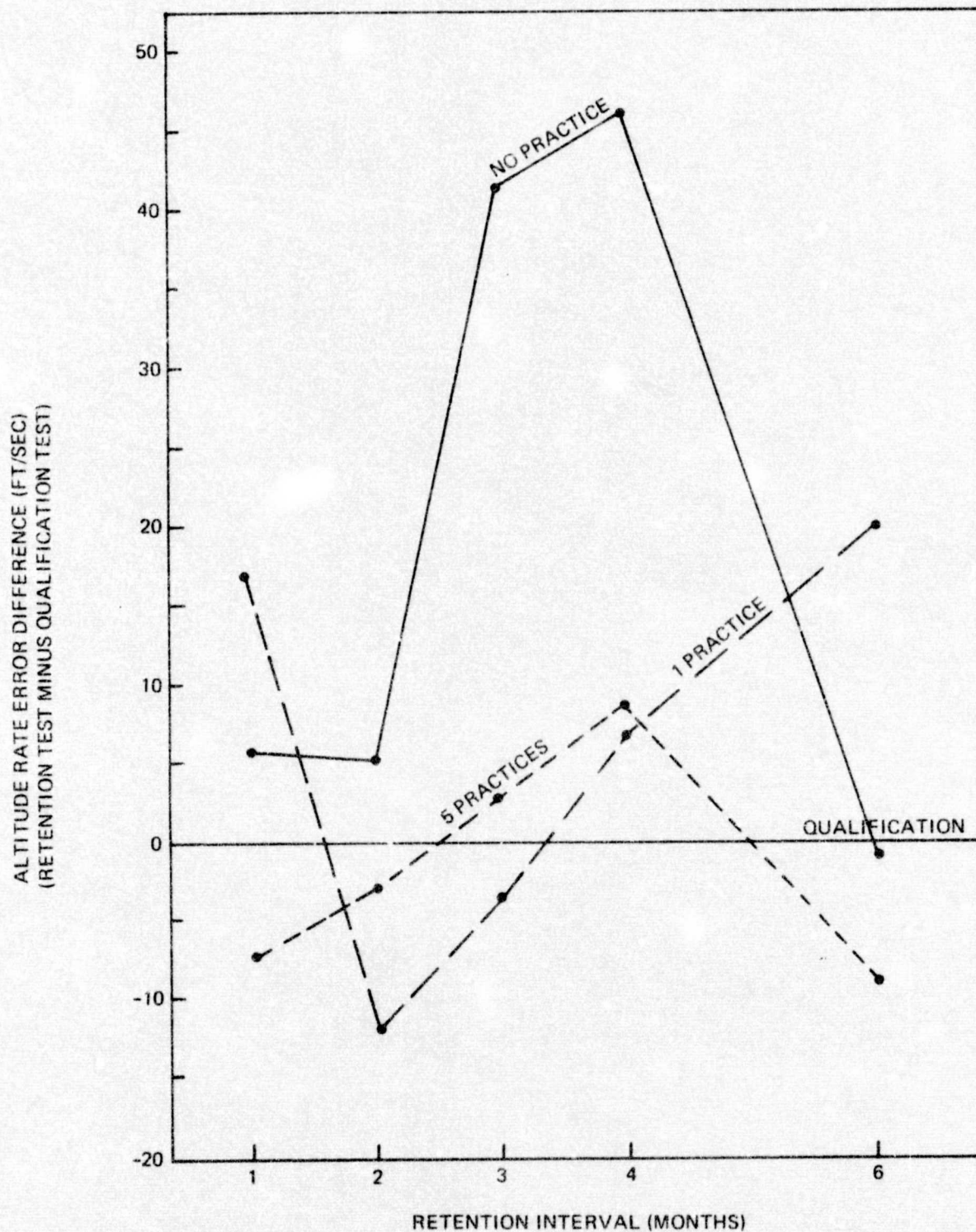


Figure 10: Altitude Rate Error at Orbit Insertion--Effect of Retention Interval and Practice on Performance

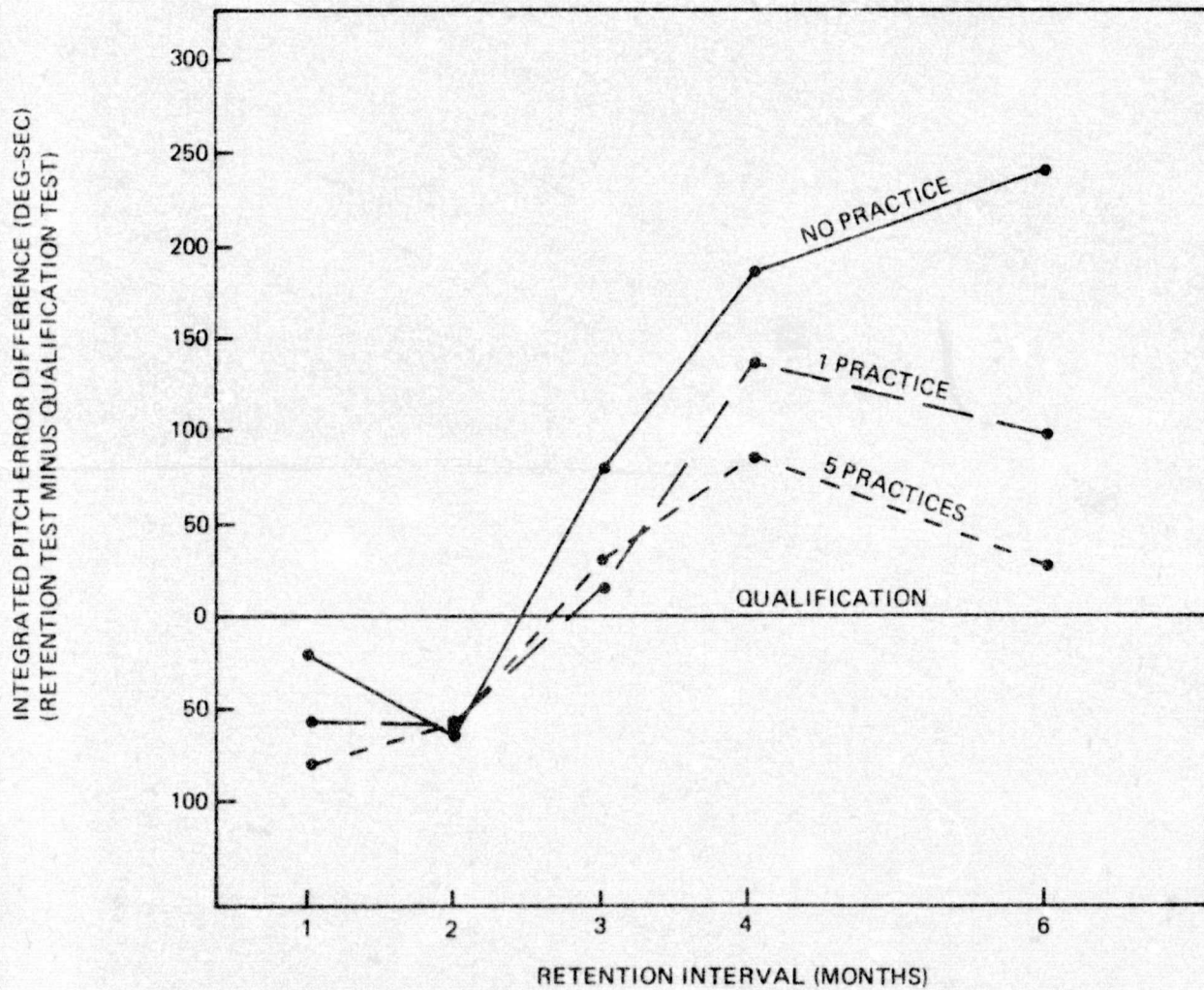


Figure 11: Integrated Pitch Error--Effect of Retention Interval and Practice on Performance

PERFORMANCE TESTS	MONTHS					ANOVA SUMMARY	
	1	2	3	4	5	SOURCE	df
	TRAINING (QUALIFICATION)						
	1ST RETENTION (NO PRACTICE)					BETWEEN SUBJECTS	24
	2ND RETENTION (1 PRACTICE)					MONTHS (M)	4
	6TH RETENTION (5 PRACTICE)					Ss WITHIN GPS	20
						WITHIN SUBJECTS	75
						TESTS (T)	3
						TM	12
						T x Ss WITHIN GPS	60
						TOTAL	99

Figure 12: Experimental Design for Effects of No Practice Retention Interval and Dynamic Warmup Practice on Skill Retention

depicted in Table 8. The general indications from the results of the analyses and plots of the data are that performance on all measures degraded with time with a general trend toward greater skill degradation after 3 to 4 months without practice. Dynamic warmup practice was generally effective in maintaining performance at the training qualification levels.

Altitude Error. The data obtained using altitude error at orbit insertion as a measure of performance showed a significant degradation occurring between the training qualification test and the retention test at the end of the no-practice interval. The duration of the retention interval was not significantly related to the amount of degradation observed. However, it can be seen in Figure 8 that the degradation was relatively minor at the shorter intervals and reached an apparent asymptote after intervals of 3 months and longer.

The magnitude of the degradation was well within the range of practical importance, reaching an average of 2700 ft of altitude error after no practice for the 3 month group. When compared to the 868 ft of average error at the end of training (qualification baseline for the 3-month group), error after the retention interval was increased by a factor of 3.1 or 1,832 ft. For the 4- and 6-month groups, error was increased by factors of 2.3 and 2.5, respectively.

Table 8: Summary of Analysis of Variance and Duncan's Tests for Effects of No Practice Retention Interval and Dynamic Warmup Practice on Flight Control Skill Retention

VARIABLE	PERFORMANCE TESTS		MONTHS	
	ANOVA	DUNCAN'S (<.05)	ANOVA	DUNCAN'S (<.05)
ALTITUDE ERROR	<.05	<u>W₅QW₁</u> NP	NS	
ALTITUDE RATE ERROR	<.05	<u>W₅QW₁</u> NP	NS	
INTEGRATED ALTITUDE ERROR	<.05	<u>W₅QW₁</u> NP	NS	
INTEGRATED PITCH ERROR	<.05	<u>W₅QW₁</u> NP	<.05	<u>31246</u>

LEGEND:

Q = QUALIFICATION
 NP = NO PRACTICE
 W₁ = 1 WARMUP PRACTICE
 W₅ = 5 WARMUP PRACTICES

ANY TREATMENTS UNDERScoreD BY SAME
 LINE ARE NOT SIGNIFICANTLY DIFFERENT

After one warmup practice performance improved at the longer retention intervals. With five warmup trials performance was without degradation at any retention interval. While the plots of the data showed some differences between qualification performance and performance at the two levels of warmup practice, the Duncan's Test failed to distinguish any significant differences.

Integrated Altitude Error and Altitude Rate Error. Significant degradation was found at the end of the no-practice interval for performance measured by integrated altitude error (Figure 9) and altitude rate error at orbit insertion (Figure 10). The Duncan's test detected

no significant differences between the qualification performance and performance at the two levels of dynamic warmup practice. Further, the Duncan's Test failed to distinguish any differences between the retention test with no practice and the retention test with one warmup practice. While not statistically significant, plots of the data showed apparent differences in no-practice skill retention as a function of duration of the retention interval. For the measure of altitude rate error, the greatest degradation occurred at the 3 to 4 month intervals and with integrated altitude error the greatest degradation occurred at the 3 month interval. With an average baseline qualification performance error of 29 ft-sec, error for altitude rate was increased by a factor of 2.5 without practice. Integrated altitude error was increased by a factor of 2.1 at the 3 month interval, from an average qualification baseline of 307 ft-sec to 653 ft-sec after no practice.

Opposite to what would be expected, the 6 month interval performance not only failed to show a large performance decrement but it failed to show any degradation whatsoever for the two performance measures. A thorough review of simulation profile stability records, test days and test log failed to uncover any unusual procedural or hardware differences which would account for the obviously unusual retention performance of the 6 month retention interval group. An explanation can be postulated, however, which involves the task orientation of the subjects in this group. There was anecdotal evidence that, after a half year, the subjects in this retention interval group had essentially forgotten how to integrate the task elements. Because the overall task load was so great, the subject locked in on following the commanded attitude and altitude rate profiles, both of which had received considerable emphasis during training. In attempting to do so during the first retention interval flight, the subjects flew a profile which had an acceptable altitude rate error and integrated altitude error.

This approach, however, is one that neglects other elements of the total task and which normally resulted in high integrated pitch error and altitude error at orbit insertion. During the first test flight, the requirement to use all of the displays to control the vehicle adequately

and consistently became reinforced and was put to use during the second flight. This one warmup practice and the concurrent awareness of the total task resulted in improved altitude error and integrated pitch error at the expense of altitude rate error on the second flight. After 5 dynamic warmups, the practice with flight control based upon all displayed information had reinstated performance on the totally integrated task.

The results of the Duncan tests detected no significant differences between performance at the two levels of warmup practice and at the end of training. The one apparent aberrant failure of dynamic practice with five warmups, depicted by the mean performance of the 2 month group as measured by integrated altitude error (Figure 9), was due to an unusually high error for one subject. His error on this test was three times greater than his no-practice performance and exceeded by a factor of 2.8, the average error of the other 2 month group subjects.

Integrated Pitch Error. The results for performance as measured by integrated pitch error were straightforward as can be seen in Figure 11. Performance was significantly degraded without practice at the longer retention intervals and the effect of warmup practice was to reduce the magnitude of the degradation. The Duncan's test failed to find any difference between qualification performance and the two levels of warmup performance. Unlike the other measures of continuous control performance, integrated pitch error showed significant differences between retention interval durations. Degradation occurred after 3 months reaching an apparent asymptotic maximum at four months, exceeding average qualification performance error by a factor of 1.7.

Effects of Static Rehearsal Practice at 3 and 6 Month Intervals

The effectiveness of static rehearsal practice methods for countering skill degradation at 3 and 6 month no-practice intervals is depicted in Figures 13, 14, 15 and 16 for the performance measures of altitude error, integrated altitude error, altitude rate error and integrated

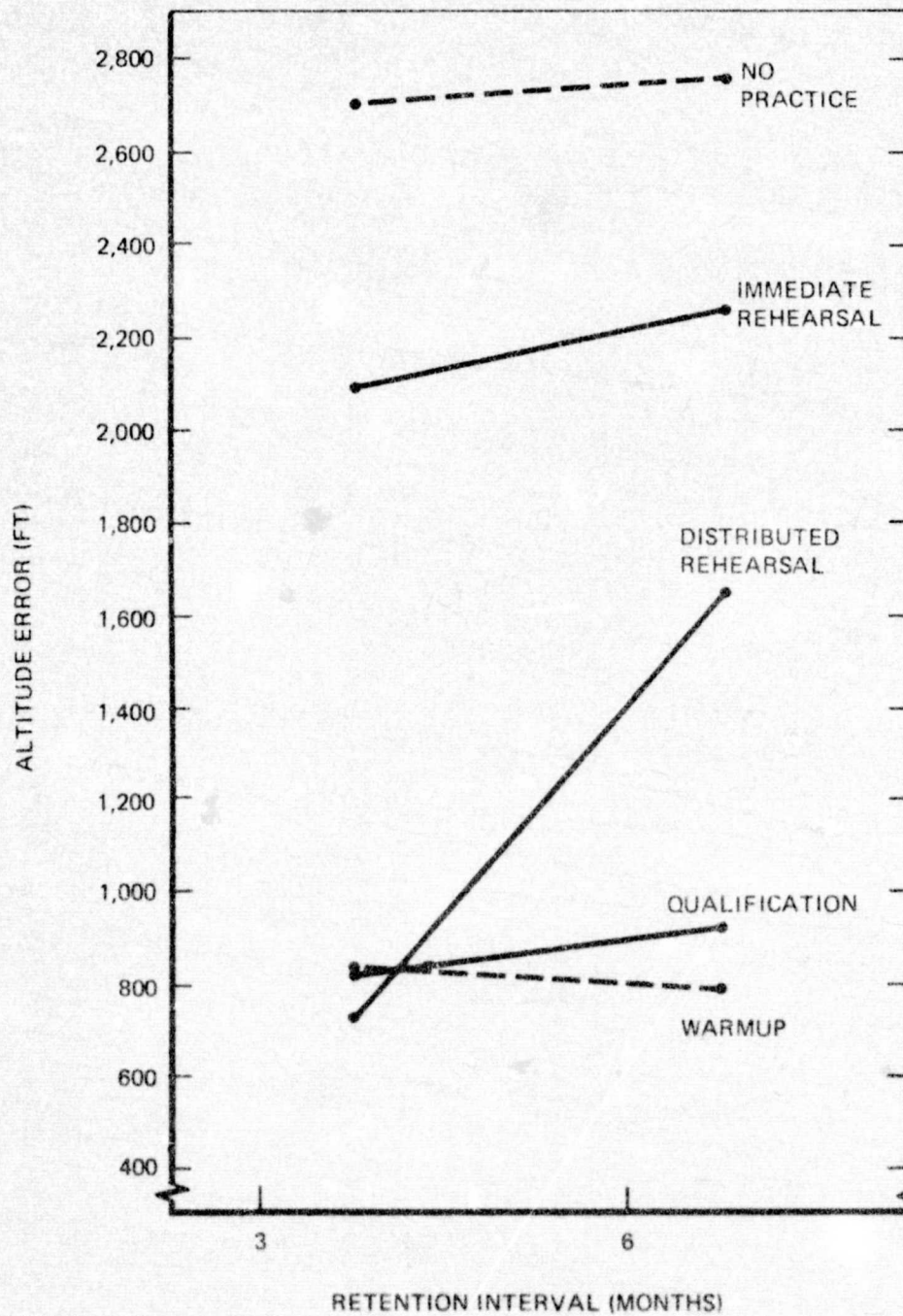


Figure 13: Altitude Error at Orbit Insertion -- Effect of Static Rehearsal Practice on Performance

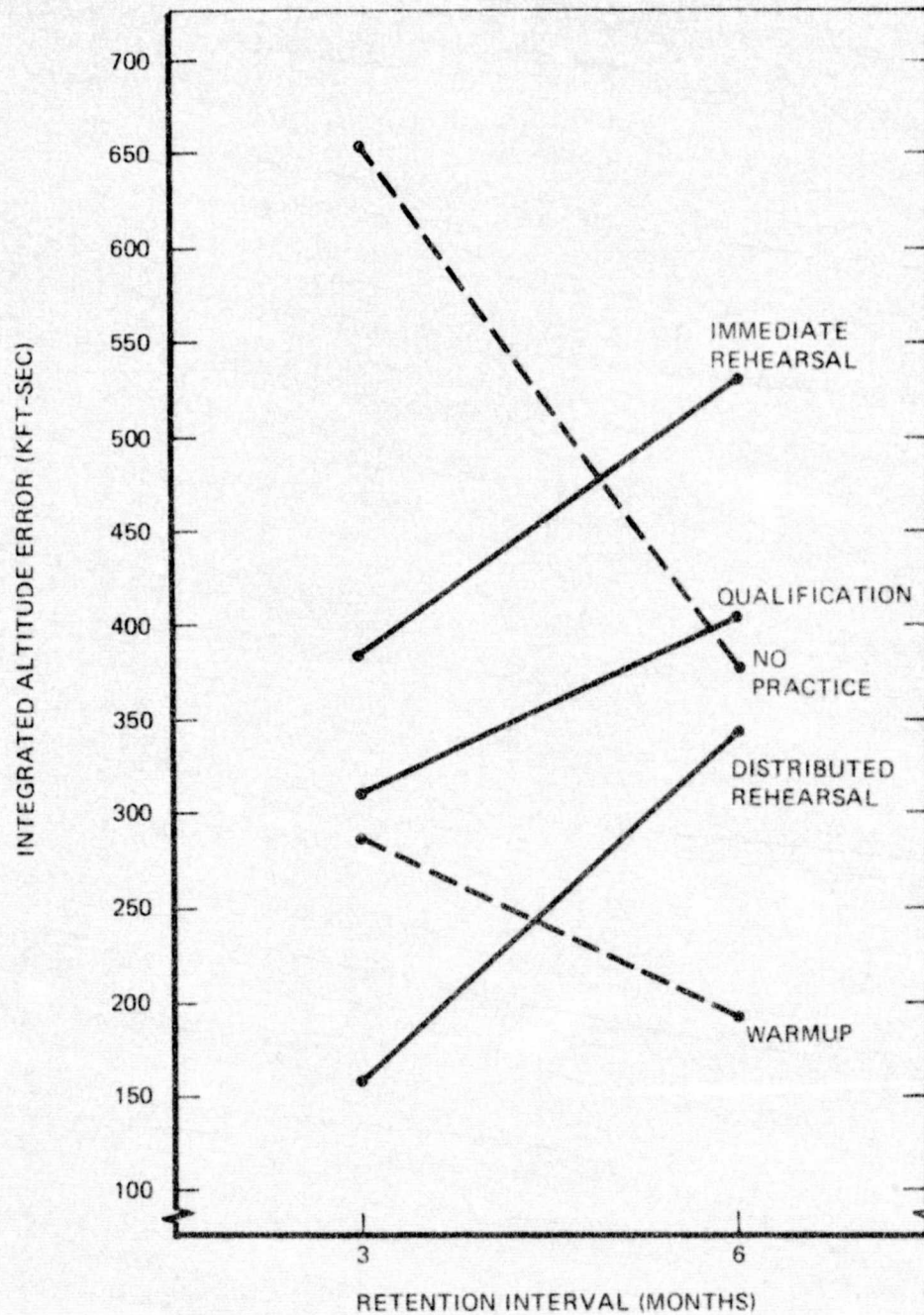


Figure 14: Integrated Altitude Error---Effects of Static Rehearsal Practice on Performance

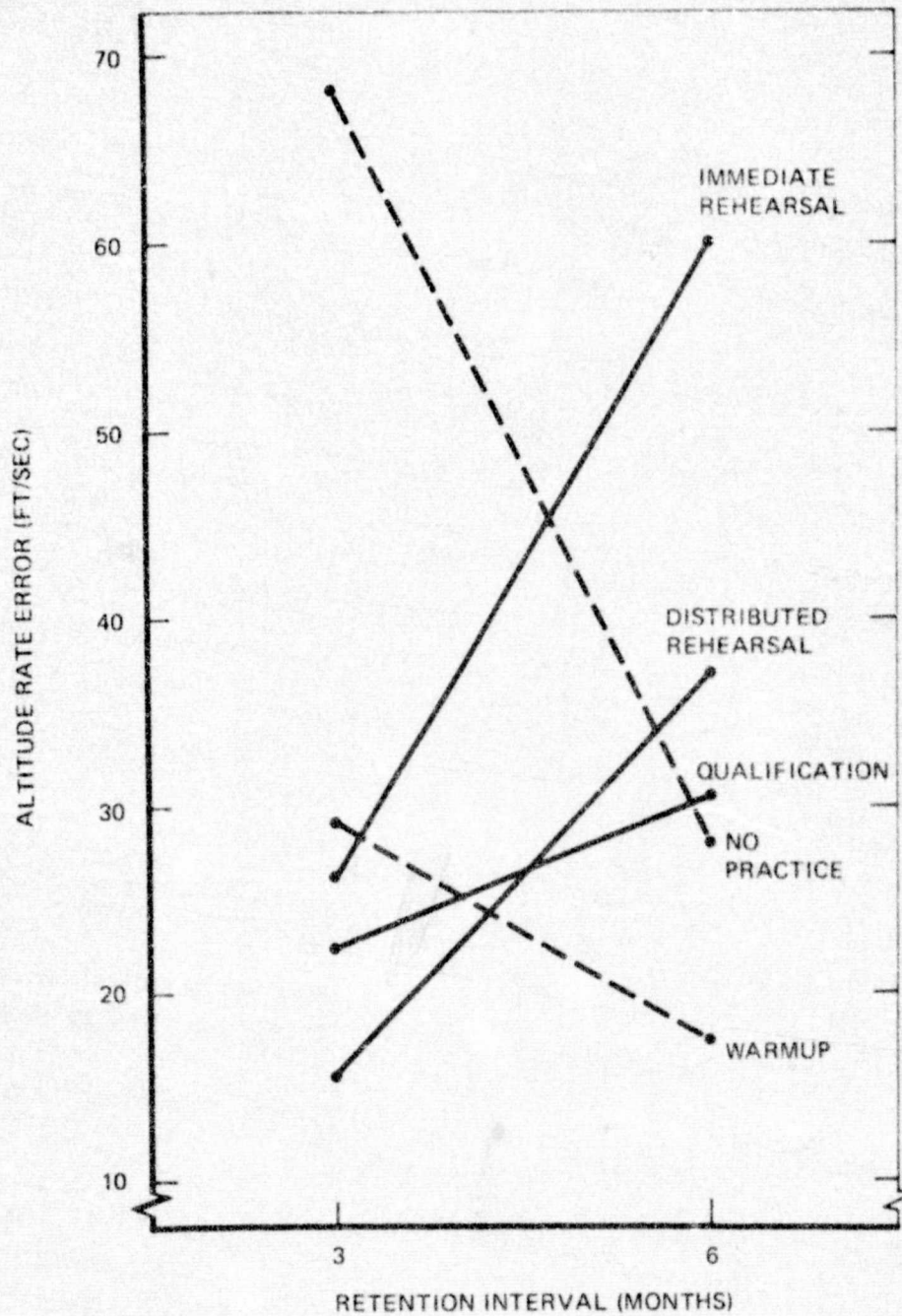


Figure 15: Altitude Rate Error at Orbit Insertion---Effect of Static Rehearsal Practice on Performance

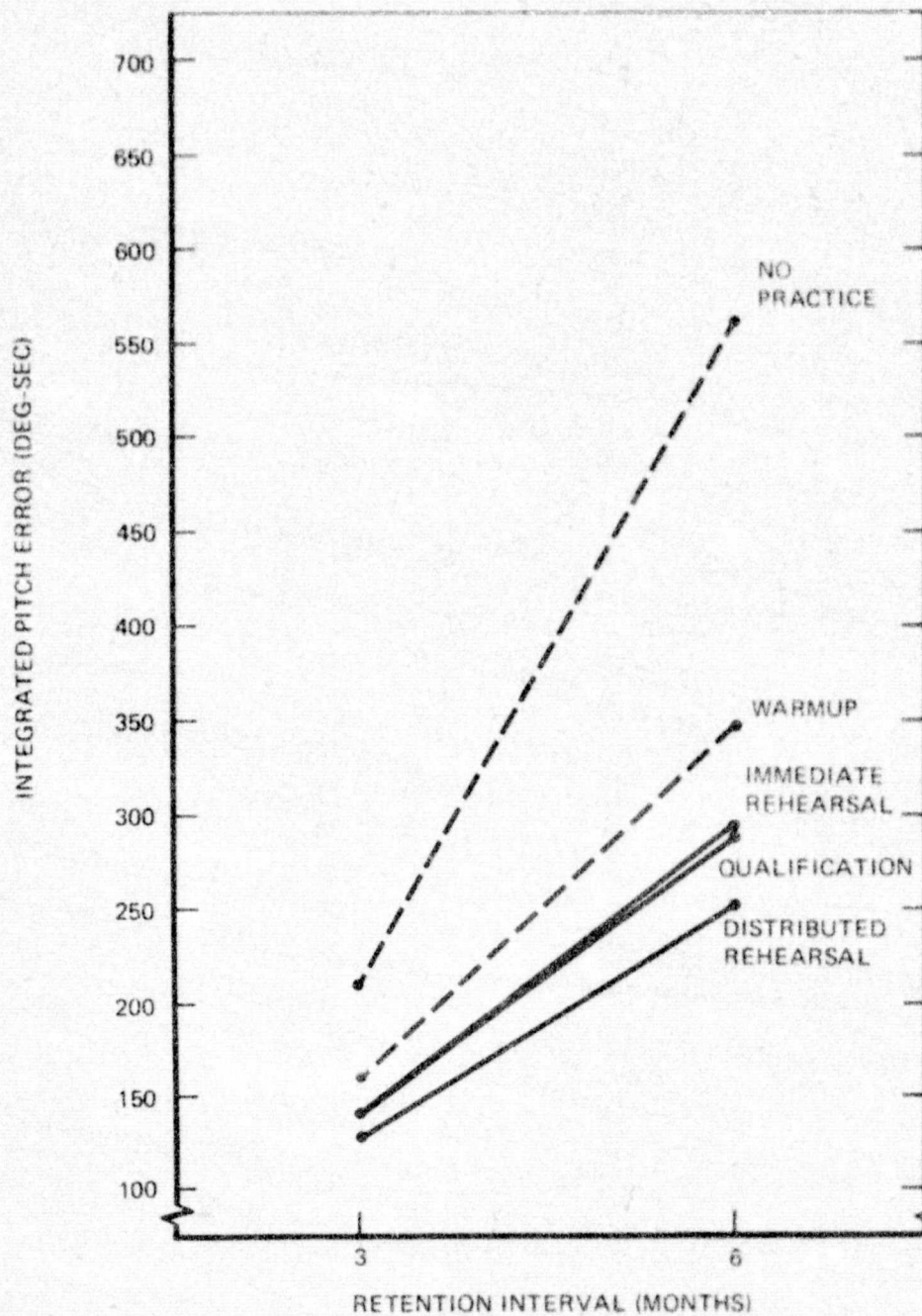


Figure 16: Integrated Pitch Error---Effect of Static Rehearsal Practice on Performance

altitude error, altitude rate error and integrated pitch error, respectively. The data plotted is absolute error measured from the desired flight profile. Two of the rehearsal groups provided the data for immediate rehearsal and distributed rehearsal at the 3 month interval and the two remaining subject groups provided the plots for distributed and immediate rehearsal practice at the 6 month interval. Included in the figures are data from the 3 and 6 month groups from the first evaluation, which provide a comparison to the error levels for no practice and five warmup practice trials. The plotted qualification performance levels are the mean of the three groups at the 3 month interval and the three groups at the 6 month interval.

The data were analyzed using a three factor analysis of variance design with repeated measures on one factor. Figure 17 depicts the analysis plan, an ANOVA summary for the between-group effects of months and practice methods, and the within-groups effects of performance tests (addition of dynamic warmup practice) on skill retention.

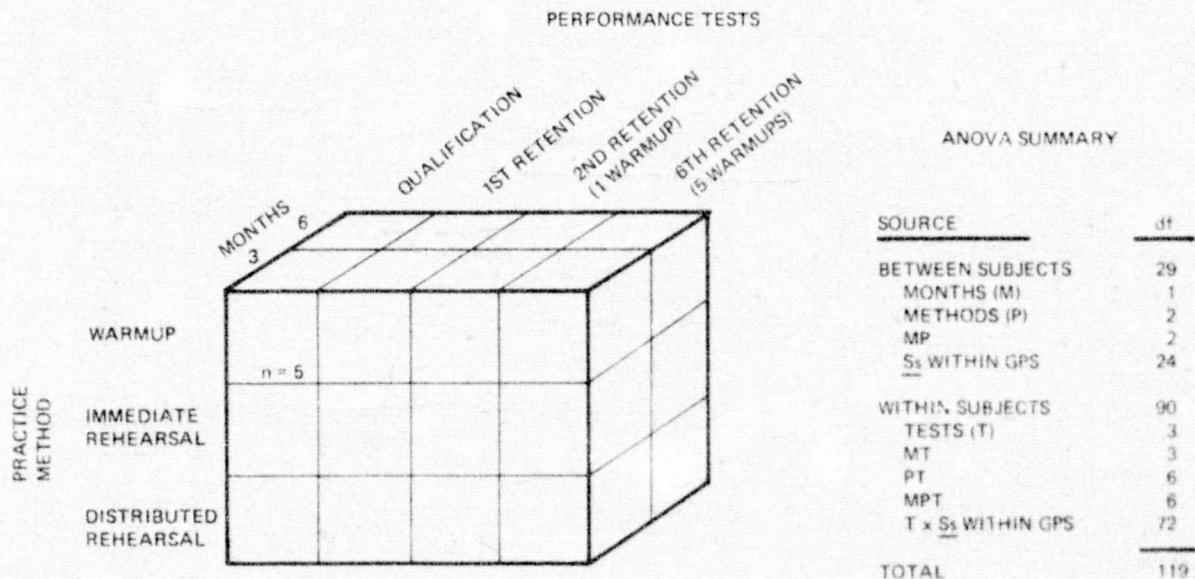


Figure 17: Experimental Design for Effect of Practice Methods on Skill Retention After Three and Six Months

In general, the results depicted in the figures indicate that static rehearsal techniques reduced the magnitude of the skill degradation, with distributed rehearsal more effective than immediate rehearsal. The performance measures responded somewhat differently to the application of the retention methods which tended to indicate that the four performance variables were measuring different elements of the task.

The beneficial effects of dynamic warmup practice and static rehearsal practice appeared to form a continuum in terms of practice method complexity. The data for altitude error showed an almost classic progression in reduction of degradation as a function of method. Except for the previously discussed deviant no-practice data for the 6 month group, data for integrated altitude error and altitude rate error generally followed the same pattern. However, the data for integrated pitch error showed practically no difference between the static rehearsal methods and dynamic warmup. While not plotted on the figures, the addition of warmup practice to the static rehearsal practice methods (2nd or 6th retention test) did not reduce skill degradation beyond that of dynamic warmup practice alone for any group.

Altitude Error. The data obtained using altitude error at orbit insertion as a measure of performance showed no significant retention differences as a function of months. The data, depicted in Figure 13, showed a strong trend ($p < .10$) towards differences between practice methods. Static rehearsal immediately preceding retention testing reduced the extent of degradation over that found for no practice. Distributed rehearsal practice further reduced the magnitude of skill degradation to the point that, at the 3 month interval, performance equalled that at the end of training. However, dynamic warmup practice was the only method which reinstated performance to training qualification levels at the 6 month interval.

Integrated Altitude Error. The effects of practice methods on the performance as measured by integrated altitude error were significant ($p < .05$). There was no difference in skill retention as a

function of months. Distributed static rehearsal practice was consistently more efficient than immediate static rehearsal practice in reducing skill degradation. As can be seen in Figure 14, immediate rehearsal failed to reinstate performance to qualification levels, while distributed rehearsal and dynamic warmup practice were sufficient to prevent skill degradation. The Duncan's test showed that the distributed rehearsal practice was significantly different ($p < .05$) from the no-practice performance levels, while immediate rehearsal was not. Distributed rehearsal plus warmup practice failed to show any improvement over 5 dynamic warmup practices alone; however, distributed rehearsal plus warmup was a significant improvement over immediate rehearsal with warmup.

The interaction between the no-practice performance and the immediate rehearsal performance is a function of the unusual 6 month group no-practice data as previously discussed and may have accounted for the absence of any statistical improvement in performance of immediate rehearsal over no-practice. The apparent discrepancy between performance with no-practice and performance with the two types of rehearsal practice was probably a function of the subject's understanding of the task at the end of the retention interval. The 6 month no-practice group, focussed on only some of the task elements, and as such, first retention test performance on integrated altitude error was unusually good. On the other hand, the subjects that received rehearsal practice had an understanding and appreciation of the total task requirements reinforced during the rehearsal, and therefore attempted to perform well on all elements of the flight control task. It must be assumed that if the subjects in the 6 month no-practice group had attempted to attend to all task elements, the no-practice data would have shown average error that was equal to or greater than that experienced by the 3 month group.

Altitude Rate Error. No statistically significant practice method differences were detected as a function of the performance measure of altitude rate error at orbit insertion. This failure to find statistical significance was probably due to the unusually low error performance

achieved with no practice by the 6 month group. There was a trend towards a difference between performance at the two retention intervals ($p < .10$). It can be seen from Figure 15 that the static rehearsal methods contributed greatly to this trend. Both immediate rehearsal and distributed rehearsal showed little degradation at the 3 month retention interval; however, at the 6 month interval both showed a greater increase in degradation. Only distributed rehearsal performance remained relatively close to qualification performance levels. As with integrated altitude error, the previously discussed aberrant data for the 6 month no-practice group made clear comparisons between practice methods difficult for the altitude rate error measure. This difficulty is relieved by the assumption that performance after 6 months would have been severely degraded had the subjects attended to the total task. As it is difficult to assume that practice of any type is worse than no practice at all, this interpretation appeared appropriate.

Integrated Pitch Error. There was little practical and no statistical difference between the practice methods and qualification performance as measured by integrated pitch error. Figure 16 shows how closely the data for the practice methods was grouped and the significant difference (Duncan's, $p < .05$) between the practice methods and no practice. Both immediate and distributed rehearsal clearly maintained acceptable performance. Warmup alone did not, and while not significantly different from the qualification performance levels, the magnitude of degradation could have practical importance. The combination of warmup and distributed rehearsal, while not plotted, resulted in the best test performance.

There was a significant interaction ($p < .01$) between methods and performance tests. The data showed relatively small differences across performance tests for the static rehearsal method groups, and for the dynamic warmup group when warmup practice was used (2nd and 6th retention test, Figure 17). Therefore, it was the large increase in degradation with no practice at the end of the 6 month retention interval which caused the significant methods by tests interaction.

There was a significant difference between performance at the 3 and 6 month intervals ($p < .01$). It can be seen in Figure 16 that each measure consistently showed greater integrated pitch error at the 6 month interval. However, from the analysis of the training data it was further noted that the baseline qualification performance of two 6 month groups was also greater. While the differences between performance measures were relatively greater at the 6 month interval, they were small. These minor increases and the absence of a significant methods by months interaction suggested that there was no practical difference between months for the practice methods.

Procedure Task

Effects of No Practice Interval and Dynamic Warmup Practice

Five procedure task operations were completed in a specified sequence during each flight with the order of the sequences reversed from flight to flight. Table 5 depicts the five procedure task sequences in the order they were completed during each flight. At the end of training, the last procedure task sequence in order (Sequence No. 4) was the most complex in terms of difficulty and number of decisions. This same procedure sequence was the first tested at the end of the retention interval. Thus the qualification performance baseline was the average performance achieved by each group at the end of training on Procedure Sequence 4. The no practice retention test data was obtained during the first flight at the end of the interval on Procedure Sequence 4.

Due to the very small amount of warmup practice afforded by one procedure task trial, ten warmup practice trials were used as the minimum amount of practice. The first procedure sequence of the third flight at the end of retention interval provided a measure of dynamic practice with ten warmups. The retention data with 20 warmup practices was obtained from the first procedure operation (Sequence 4) of the fifth retention test flight.

The effects of the no practice interval and the effects of dynamic warmup practice were evaluated using both the time and error measures

of procedure task performance. The data were analyzed with the same two factor analysis of variance design used for the continuous task (Figure 12). The results of these four ANOVA's and the Duncan's Multiple Range Test are depicted in Table 9.

Table 9: Summary of Analysis of Variance and Duncan's Tests for Effects of No Practice Retention Interval and Dynamic Warmup Practice on Procedure Skill Retention

VARIABLE	PERFORMANCE TEST			MONTHS	
	ANOVA	DUNCAN'S (<.05)		ANOVA	DUNCAN'S (<.05)
INITIAL RESPONSE TIME	<.01	<u>QW₂₀W₁₀</u>	NP	NS	
DECISION TIME	<.01	<u>QW₂₀W₁₀</u>	NP	NS	
SEQUENCE TIME	<.01	<u>QW₂₀W₁₀</u>	NP	NS	
TOTAL TIME	<.01	<u>QW₂₀W₁₀</u>	NP	NS	<u>1 2 3 4 6</u>

Legend:

Q = QUALIFICATION

NP = NO PRACTICE

W₁₀ = 10 WARMUP PRACTICE

W₂₀ = 20 WARMUP PRACTICES

ANY TREATMENTS UNDERScoreD BY SAME LINE ARE NOT SIGNIFICANTLY DIFFERENT

In general, performance degraded significantly at the end of retention interval for all time measures of performance. Figures 18, 19, 20 and 21 depict the effects of retention interval duration and dynamic warmup practice on procedure task performance as measured by initial response time, average decision time, average sequence time and total procedure time, respectively. There was an apparent trend towards greater skill degradation with longer no practice intervals. The absence of any differences between qualification and the retention tests with warmup prevented statistical detection of months effects for the no-practice data. However, as can be seen from plots of the data, retention performance on all measures showed a sharp increase in degradation after 4 months without practice.

Total Procedure Time. As an overall measure of procedure task performance, the total time required to perform the most complex procedure sequence provided a dramatic demonstration of performance

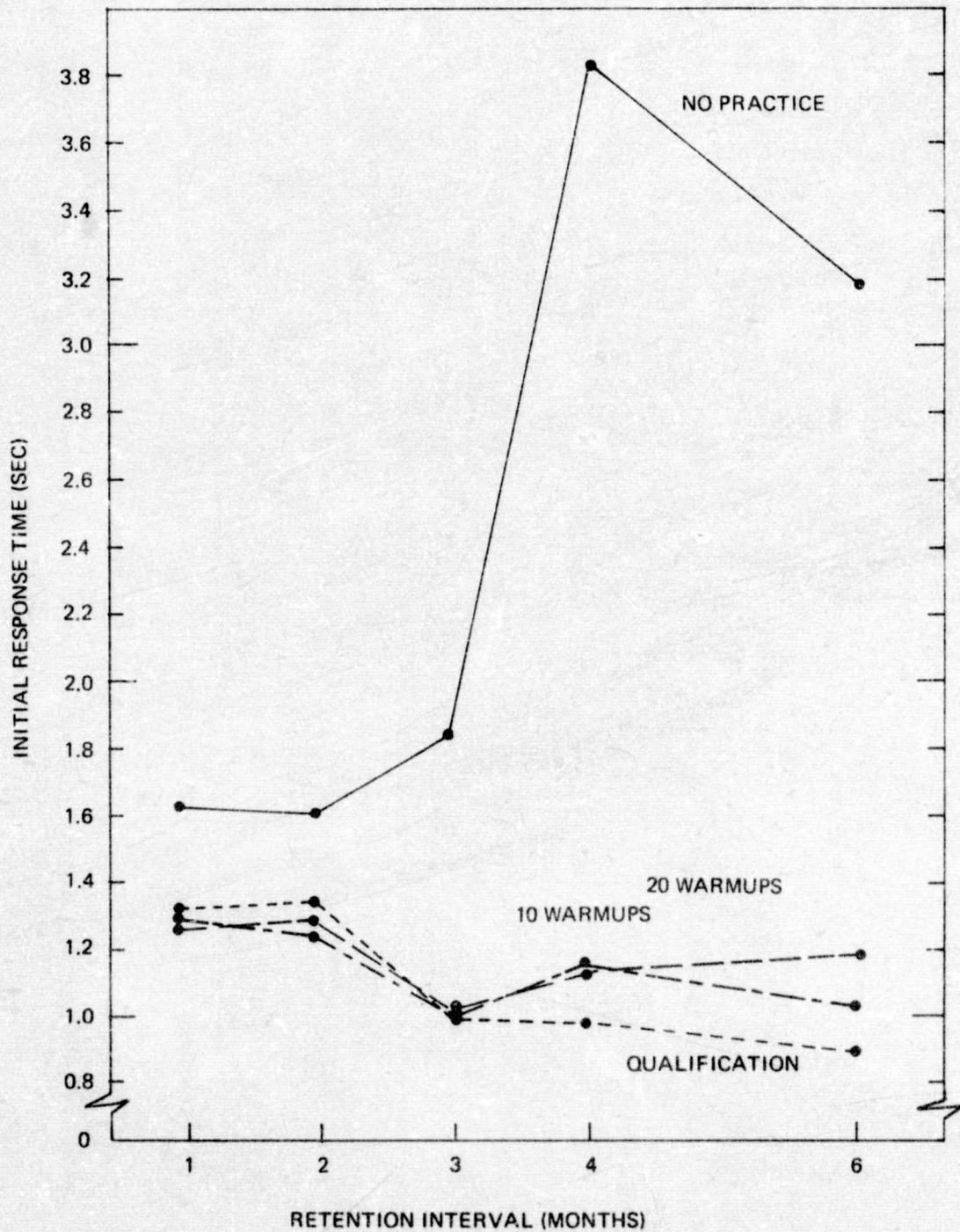


Figure 18: Initial Response Time -- Effect of Retention Interval and Practice on Performance

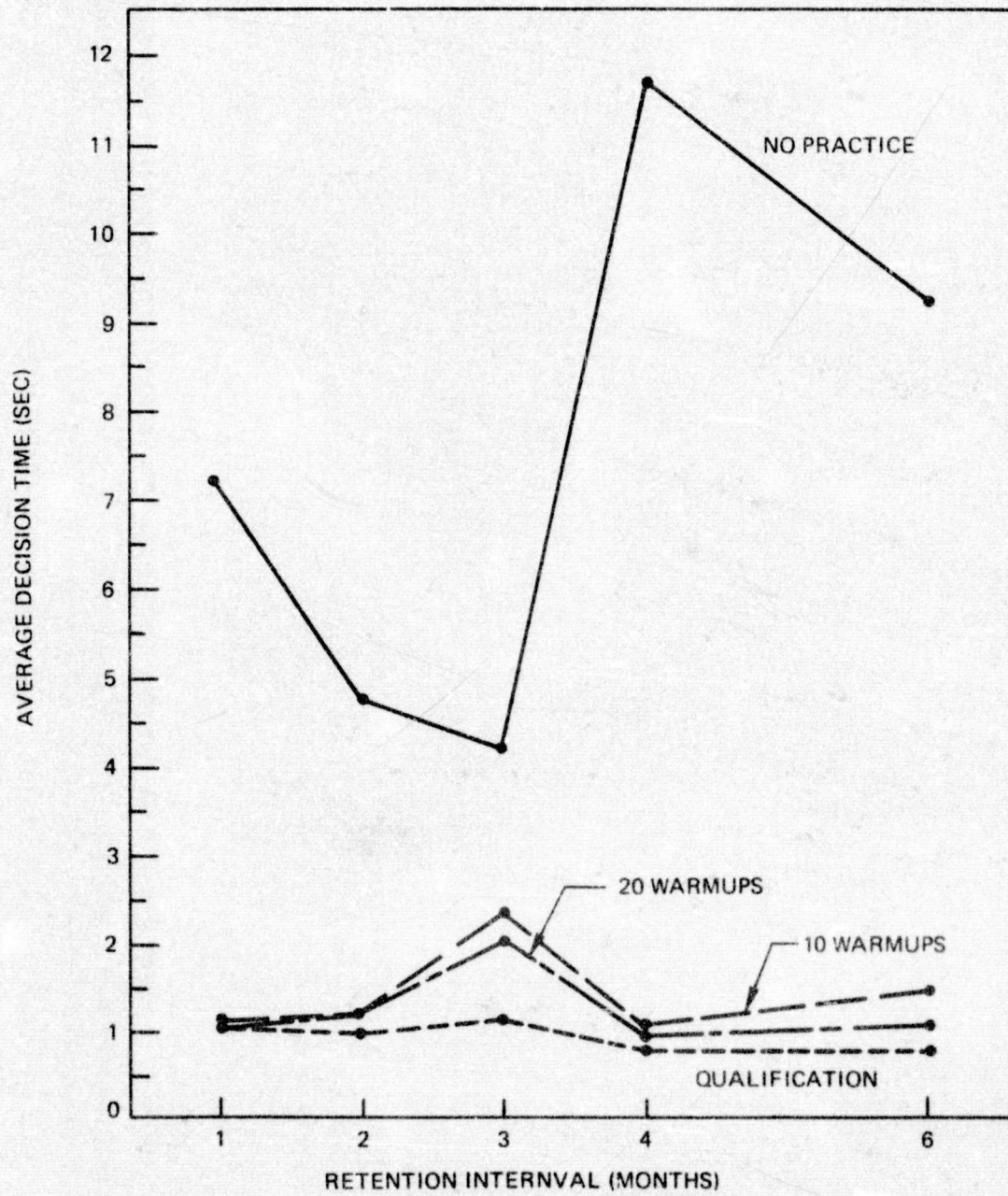


Figure 19: Average Decision Time -- Effect of Retention Interval and Practice on Performance

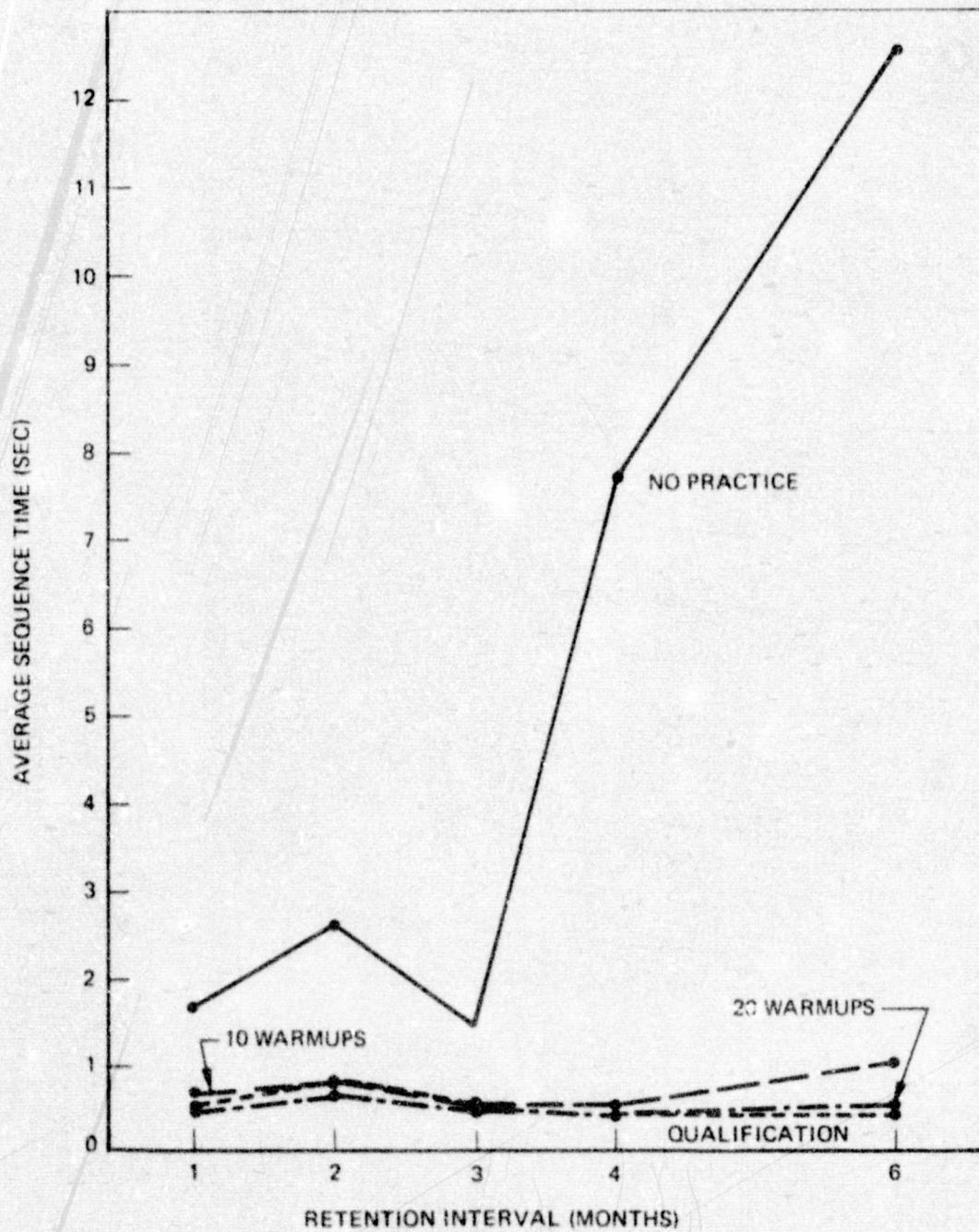


Figure 20: Average Sequence Time -- Effect of Retention Interval and Practice on Performance

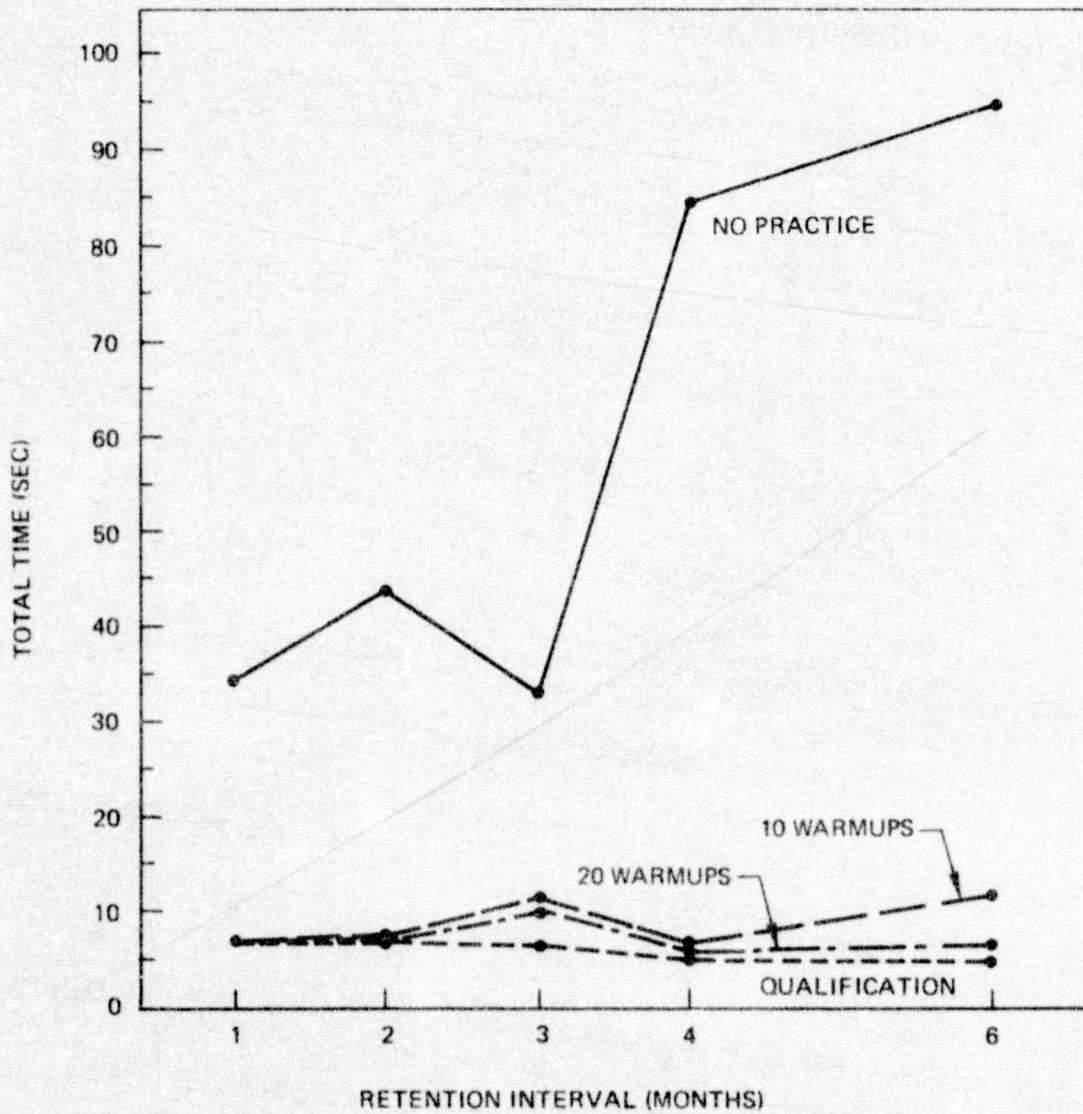


Figure 21: Total Procedure Time -- Effect of Retention Interval and Practice on Performance

degradation and warmup recovery (Figure 21). At the shortest retention interval without practice (1 month), the average total time to complete the procedure sequence was approximately five times greater than that required at the end of training. This magnitude of degradation continued through the 2 and 3 month no-practice retention intervals. A dramatic increase in degradation was seen after 4 months without practice, where the total time required to complete the procedure was 17 times greater than that the end of training. When ten or more dynamic warmup procedure task trials preceded the retention test, no appreciable degradation in performance was found at any retention interval.

There was a significant performance tests by months interaction ($p < .05$). From the plot of the total time data in Figure 21, it can be seen that there was essentially no difference between qualification and warmup performance, and that performance was constant across retention intervals. The no practice performance was degraded, and this degradation increased with the longer retention intervals. The significant tests by months interaction detected these differences and indicated that no practice performance degradation increased as a function of the retention interval duration.

Initial, Decision, and Sequence Time. The same general effects of the practice methods and retention intervals were seen for the discrete elements of procedure task performance: initial reaction time, decision time and sequence time. Initial response time was a very basic measure of psychomotor performance which required a minimum of task understanding or decision making. The pilot only had to remember, and then make, one response to the flashing warning light. With such a basic measure of psychomotor performance, the magnitude of skill degradation was not expected to be very large even over the longest retention intervals. The results depicted in Figure 18 showed that this was, in fact, the case, with response time increasing from about 1 second to 1.8 seconds at the 3 month interval. However, even with this basic measure, performance degradation increased sharply at intervals of 4 months and longer without practice.

Decision time performance as depicted in Figure 19 showed a greater magnitude of degradation without practice than did initial response time. This was as expected, because as a performance measure, decision time required greater cognitive involvement, memory of multiple decision choices and responses which were more susceptible to the degrading influences of time. Up to intervals of 3 months, decisions required from four to seven times longer than that at the end of training. Similar to the measures of total and initial response time, average decision time showed a large increase in degradation after four or more months without practice. This degradation amounted to an increase in average decision time of from 0.8 seconds at qualification to 11.7 seconds after 4 months without practice. Considering that each procedure required four separate decisions, degradation of this magnitude was of considerable practical importance.

Sequence time which required remembering a set order of sequential responses showed a level of degradation that was intermediate between initial and decision times for the first 3 months without practice. After 4 months, the ability to remember the order of responses degraded rapidly as can be seen by the sharp increase in average sequence time depicted in Figure 20.

Dynamic warmup practice resulted in reinstating performance to the levels achieved at the end of training for each of the discrete elements of procedure task performance. The Duncan's test showed no significant difference between qualification levels of performance and performance at the 2 levels of warmup practice. Significant differences were found (Duncan's: $p < .05$) between these three performance tests and the no-practice performance test.

Error Performance. Procedure task performance as measured by procedural errors likewise showed degradation after intervals of time without practice. Both sequence and decision errors were found to occur with no-practice retention intervals of 2 months or longer. The average number of sequence and decision errors are depicted in

Figure 22 with the combination of both showing the total number of errors committed at each retention interval. No errors occurred for the shortest (1 month) no practice interval, and with intervals of 2 months or longer the number of errors remained relatively constant.

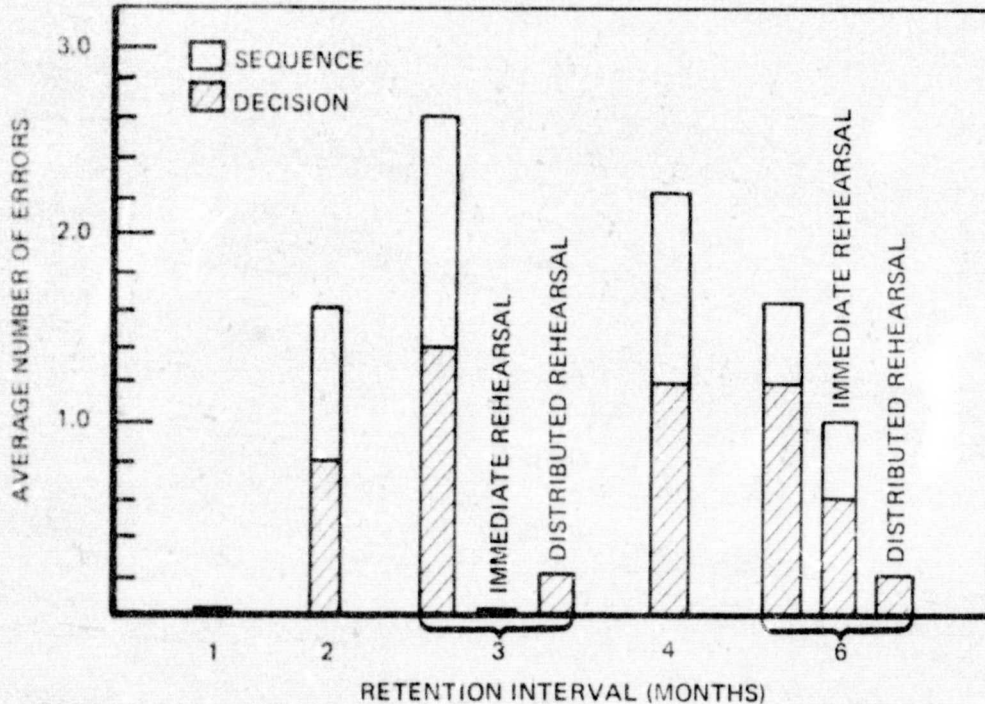


Figure 22: Average Number of Procedural Errors on First Trial After Retention Interval Without Practice and With Rehearsal Practice at 3 and 6 Month Intervals

Included in Figure 22 are the average number of errors committed by the immediate and distributed rehearsal groups at the 3 and 6 month retention intervals. It can be seen that decision errors accounted for more than half of the total error occurrences under the no practice conditions. At the 3 month retention interval, the static rehearsal practice methods eliminated all sequence and virtually all decision error occurrences. At the 6 month interval, distributed rehearsal practice eliminated sequence errors and virtually all decision errors.

While not plotted, dynamic warmup practice eliminated the occurrence of all errors except at the 6 month interval, where an average of 0.4 errors were committed per procedure trial, equally divided between sequence and decision errors. No errors occurred for any combination

of static rehearsal practice and dynamic warmup practice.

Effects of Static Rehearsal Practice at 3 and 6 Month Intervals

The effectiveness of static rehearsal practice methods for countering skill degradation at the 3 and 6 month no-practice intervals was evaluated with the same experimental design used for the continuous control task. The analysis plan for the three-factor analysis of variance design with repeated measures on one factor is depicted in Figure 17. Included is the ANOVA summary for the between-group effects of months and practice methods, and the within-groups effect of performance tests (addition of dynamic warmup practice) on skill retention. As with the continuous control task evaluation, the data for this evaluation were obtained from the immediate rehearsal and distributed rehearsal groups at the 3 month interval and the comparable two groups at the 6 month interval. Included in the evaluation were the 3 and 6 month warmup group data to provide no-practice and warmup practice error level comparisons. All qualification performance levels plotted in the figures were the mean of the three groups at the 3 month interval, and the 3 groups at the 6 month interval.

Initial Response Time. Initial response time as a function of practice methods is depicted in Figure 23 for the 3 and 6 month retention intervals. The data show no practical or significant differences between practice methods at either the 3 or 6 month retention interval. The main effect of performance tests indicated a significant ($p < .005$) degradation of performance on the first performance test at the end of the retention interval. The significant degradation was a function of the no-practice data for the warmup group as shown by the significant tests-by-methods interaction ($p < .05$). No significant or practical differences were found between warmup and the combination of static rehearsal methods with warmup. As would be expected with such a simple measure of performance as initial response time, all techniques reinforced the relationship between the stimulus and appropriate response, essentially reinstating performance to qualification levels. While not significant, additional warmup practice trials further reduced initial response time after the retention interval, and

the combination of warmup and either method of static rehearsal totally eliminated degradation.

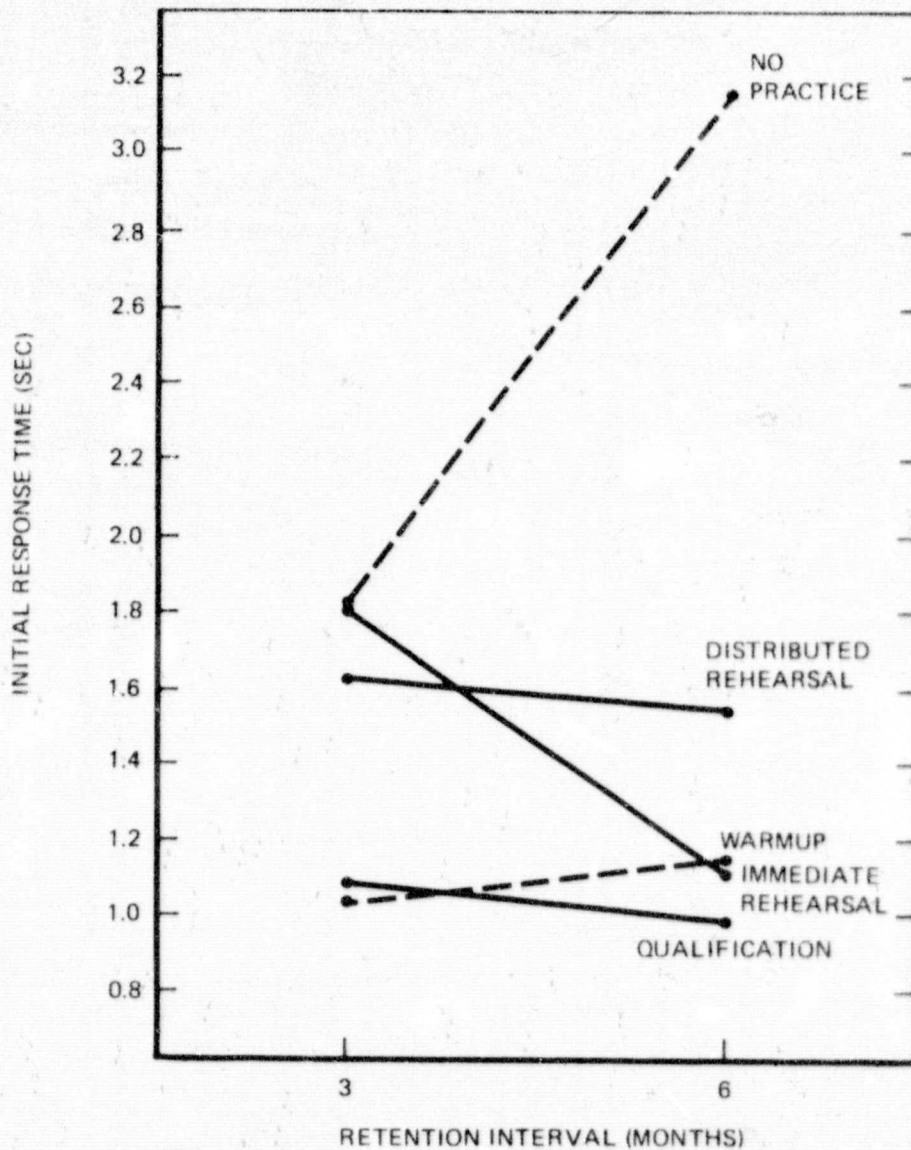


Figure 23: Initial Response Time---Effect of Static Rehearsal Practice on Performance

Decision Time. The average time required to make each of the four decisions in the procedure task sequence is plotted as a function of retention method and interval in Figure 24. The main effects of retention methods and performance tests were significant ($p < .005$). Similarly, the months by performance tests, retention methods by performance tests and the months by methods by tests interactions were all significant ($p < .005$).

The impact of all of these effects are revealed by Figure 24. The methods effect showed that immediate rehearsal and distributed rehearsal groups had less degradation than the warmup group (Duncan's $p < .05$). The test effect, which indicated significant degradation on the first retention flight, coupled with a significant methods by tests interaction indicated that it was the no-practice data for the warmup group that caused the significant degradation differences. Both the months by tests and months by tests by methods interactions indicated the greatest degradation was on the first performance test for the 6 month no-practice data. While not significant, degradation was not totally eliminated until the combination of both warmup and rehearsal was used.

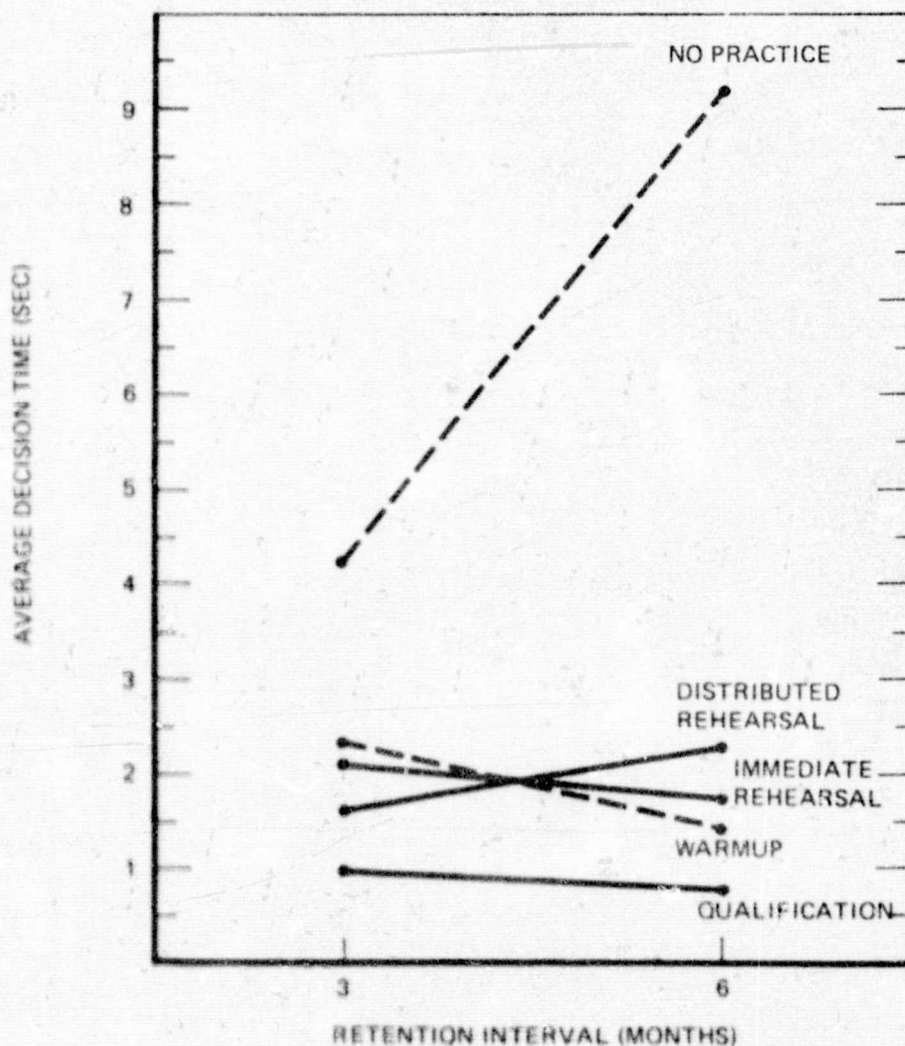


Figure 24: Average Decision Time---Effect of Static Rehearsal Practice on Performance

Sequence Time. The data for average sequence time was strikingly similar to that found for initial response time with one notable exception, the relative degradation at the 6 month interval without practice was dramatically greater (Figure 25). The significant main effect of tests ($p < .025$) indicated severe degradation on the first retention test with an improvement in performance with addition of warmup practice. A strong trend towards a significant methods by tests interaction ($p < .10$) indicated that the test effect was due to the no-practice data for the warmup group. The analysis found no significant differences across methods; however, it was noted that either increased amounts of warmup practice or the addition of warmup practice to either static rehearsal method reinstated performance to the qualification levels (Duncan's, $p < .05$).

Total Procedure Time. The effects of rehearsal methods on the total time required to complete the procedure task is depicted in Figure 26. The data showed that, as a summation of the discrete elements of procedure task performance, the total procedure time data were very comparable to the results described above. The main effects of performance tests indicated that significant degradation occurred on the first test at the end of the retention interval ($p < .005$), and that performance was reinstated by the inclusion of additional warmup practice. The significant methods effect ($p < .005$) showed that this degradation was due to the warmup group which showed poorer retention performance as compared to the rehearsal groups.

As can be seen in Figure 26 and the results of the significant methods by tests interaction ($p < .005$) further indicated that this degradation was due to the no-practice data of the warmup group. The months by tests ($p < .005$), months by methods ($p < .05$), and the three way interaction ($p < .01$) indicated that there was a dramatic increase in degradation for the warmup group after 6 months without practice. The results of the analyses and the plots of the data indicated no significant or practical differences in performance between the two rehearsal groups and the warmup group. Further, no significant differences were detected between qualification performance and performance at the end of the retention interval with practice of any type.

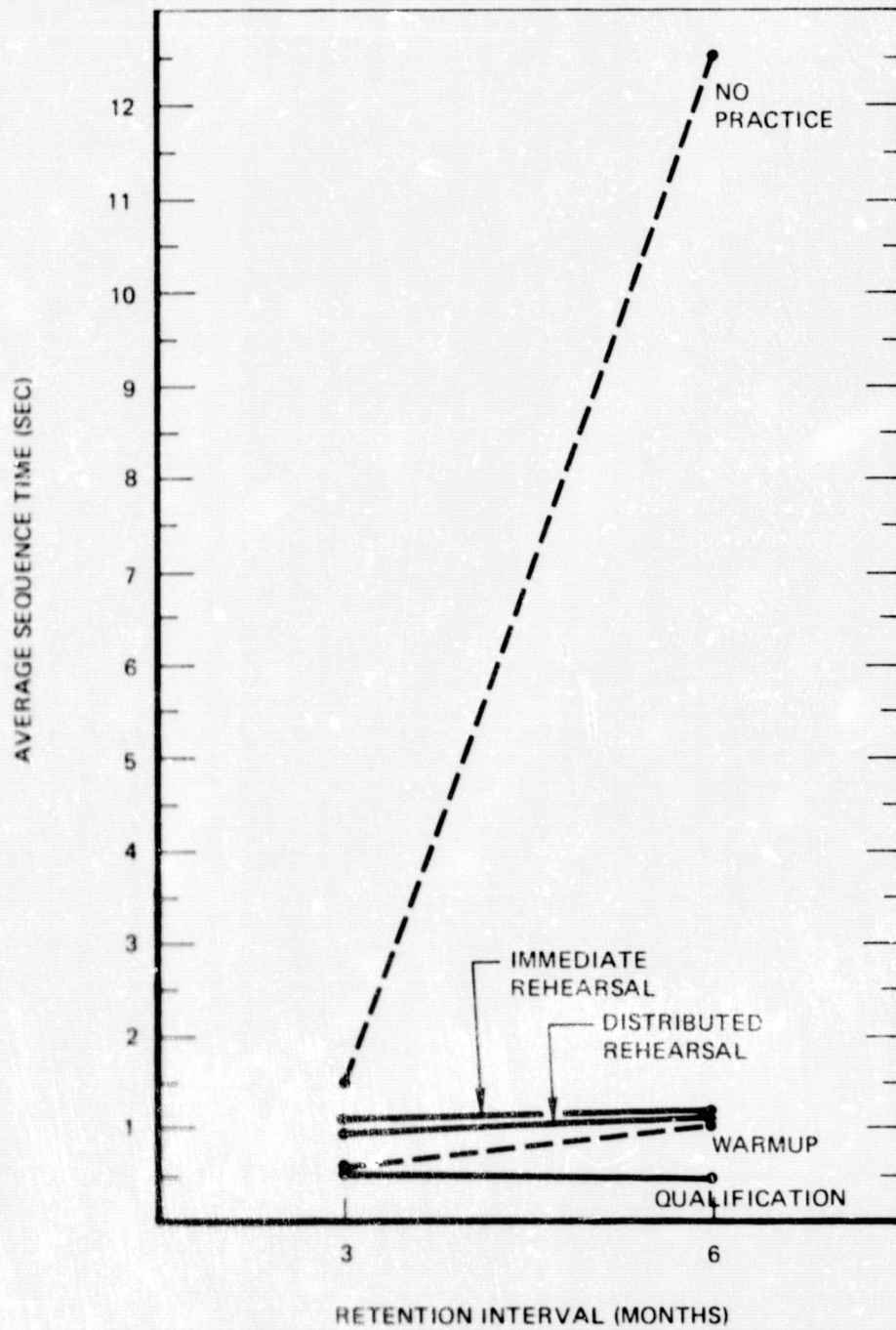


Figure 25: Average Sequence Time -- Effect of Static Rehearsal Practice on Performance

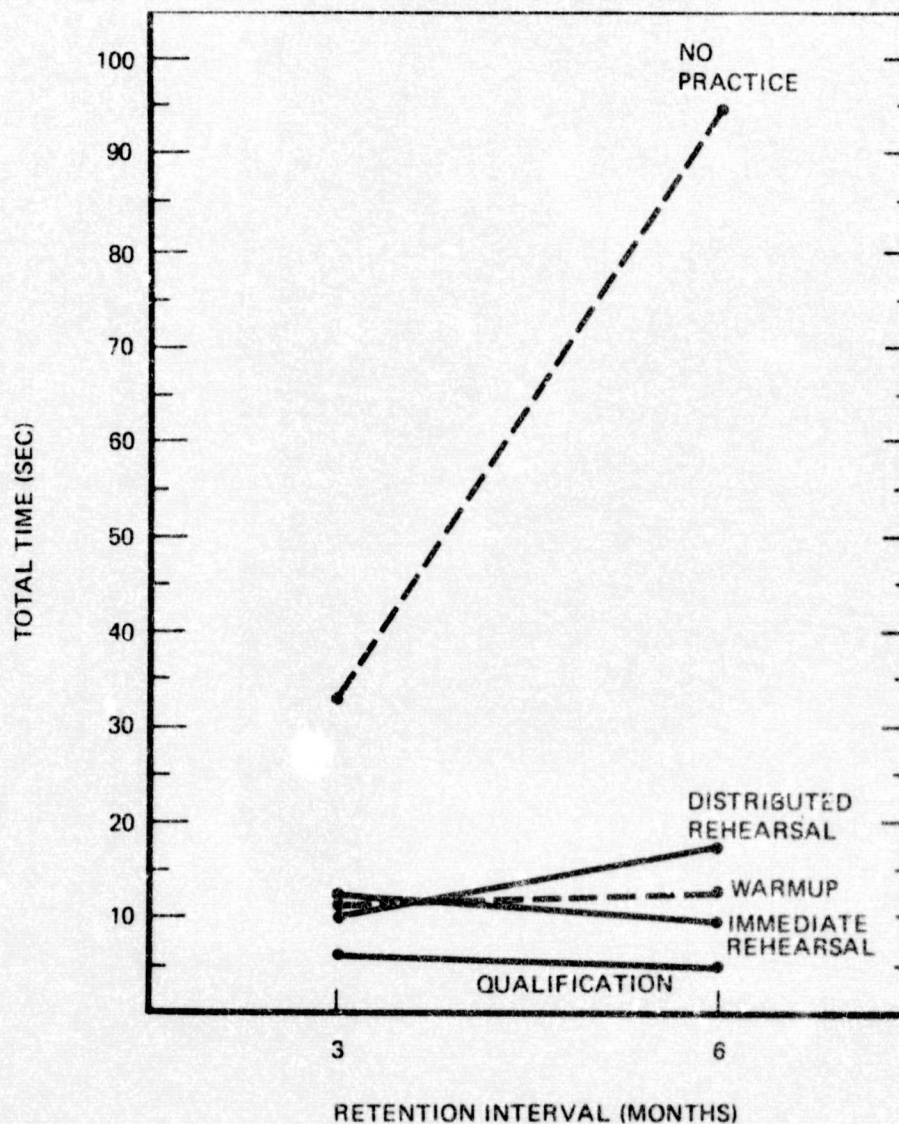


Figure 26: Total Procedure Time -- Effect of Static Rehearsal Practice on Performance

Although the difference between qualification performance and performance at the end of the retention interval with practice was not significant, the levels of practice depicted in Figure 26 were not completely sufficient to reinstate performance to the qualification levels. Generally speaking, even with the benefits of static or dynamic practice, approximately twice the total time was required to complete the procedure task at the end of the retention interval than was required at the end of training. While not plotted, increased amounts of warm-

up practice or the addition of warmup to the static rehearsal practice methods further reduced degradation levels resulting in performance virtually equivalent to that obtained at the end of training.

Distributed Warmup Practice at 3 Month Interval

Subject Group 1 provided data for the evaluation of no practice and dynamic warmup practice for the 1 month retention interval. This same group was retested at the end of 2 and 3 months, thereby providing dynamic warmup practice distributed over the 3 month retention interval. No difference in degradation was detected at the 3 month interval between this distributed warmup practice and the warmup practice provided immediately before retention testing for any measure of performance.

4. DISCUSSION

The small number of subjects represented in each treatment group hindered a completely valid statistical representation of the results. Fortunately, sufficient significant differences and strong trends were detected to provide a reasonable representation of the results. Where differences of large magnitude occurred without statistical significance, the shape of the performance measure degradation function across conditions often indicated that probable significance would have been obtained with a larger sample size. Further, in some cases, experience and judgement were used to determine if the differences were of any practical significance or importance.

Viewed across all performance measures, significant degradation in performance occurred after intervals of no practice for both the continuous control and procedure tasks. In general, continuous control performance degradation was relatively moderate until 3 months had elapsed without practice. At that time, degradation increased sharply with average error 1.7 to 3.1 times greater than at the end of training. The data suggested that skill degradation had reached its peak at about 4 months.

Procedure performance, on the other hand, showed strong degradation after only 1 month without practice. This significant level of degradation remained relatively constant through 3 months without practice. Similar to the continuous control task, procedure performance showed a sharp increase in degradation at 4 months. Further, the relative magnitude of procedural skill degradation was greater than that for the continual control task. As an overall measure of task performance, total procedure time was almost five times greater after the shortest retention interval than at the end of training and was 17 times greater after 4 months.

The capacity of the static rehearsal and dynamic warmup practice methods to maintain performance was closely associated with the measure of task performance. For each task, dynamic warmup was

required to maintain skills as measured by some performance variables while static rehearsal was sufficient for others. In some cases, degradation was not completely eliminated until a combination of both methods was used.

For the continuous control task, distributed rehearsal prevented degradation at the 3 month interval for all measures of performance. It is important to note that the rehearsal had to be repeated at regular intervals during the retention period. A single immediate rehearsal practice at the end of the retention interval was insufficient to maintain performance. After 6 months, distributed rehearsal was sufficient to maintain performance for only two of the four measures: integrated altitude error and integrated pitch error. Dynamic warmup practice maintained acceptable performance for three of the four flight control measures after 6 months. While not statistically significant, and of questionable practical importance, warmup failed to maintain performance as measured by integrated pitch error. Considering all measures of control task performance, the results showed that at 6 months, warmup practice or a combination of warmup and dynamic rehearsal practice was required to prevent the occurrence of degradation of skills.

Procedure task performance was effectively maintained by all practice methods in terms of the time measures. While some differences between methods were observed, none were of practical importance. Interestingly, of the individual methods, only dynamic warmup was able to totally eliminate degradation; and then, only for initial response time at the 3 month interval. As with the continuous control task, the combination of warmup and rehearsal prevented degradation for all measures. In terms of the error measures, both rehearsal and warmup reinstated performance equally. The general overall result, from both a statistical and practical viewpoint, was that rehearsal techniques effectively maintained procedural performance at both the 3 and 6 month retention intervals.

The results reflected a fundamental difference in skill degradation between the procedure and continuous control tasks. While both tasks showed a similar degradation function across retention intervals, the relative degradation of the procedure task was consistently greater. The magnitude of the degradation was clearly unacceptable at the shortest interval for the procedure task, and at a level which was not found for the continuous control task until 3 months without practice. At 3 to 4 months, when both tasks showed the sharply increased loss in performance, the relative degradation magnitude of the procedure task was five times greater than the continuous control task. Further, this difference between the tasks was highlighted by the finding that static rehearsal methods countered degradation effectively for the procedure task, while dynamic warmup practice appeared necessary for retention of the continuous control task.

It was apparent that these differences between procedure and continuous control tasks were not solely a function of the general task type, but were a function of the type of performance that was being measured. Within each task, the measures of skill were sensitive to different elements of task performance, as was shown by the different retention interval and retraining effects.

These task performance elements can be viewed across a continuum from highly cognitive information processing and decision making to discrete and continuous psychomotor performance. Procedural tasks generally involve skills more toward the cognitive end of the spectrum while flight control skills are more closely oriented toward the motor. Therefore, it can be assumed that retraining methods which involve narrative, verbal, or pictorial task rehearsal, being essentially cognitive in nature should be most appropriate for procedure tasks, while the interactive manual control practice afforded by dynamic warmup should be appropriate for continuous control tasks.

However, skill degradation was found to vary as a function of practice method, differently for the performance measures of the same task. For example, the effects of warmup and rehearsal formed a continuum

as a function of performance measure for the continuous control task. The data for altitude error showed an almost classic progression in the reduction of degradation as a function of method, while for integrated pitch error there was apparently little difference between the methods with rehearsal being adequate. Performance measured by altitude rate error and integrated altitude error was in the middle of the continuum, generally following the expected trend, but obviously benefitted by rehearsal. Rehearsal strongly affected continuous control skill elements which were measured by these two variables. Further the benefit was most strongly observed for those subjects who had these skill elements repeatedly reinforced in their memory during distributed rehearsal.

Since one aspect of the control task required the subjects to maintain the appropriate altitudes and rates commanded on the profile card, the card had to be regularly scanned throughout the mission. The net result was that the task time available for the instrument monitoring, information integration and control response was reduced and the opportunity for error was increased. Those subjects provided with distributed rehearsal had the altitude and altitude rate profiles so well in mind that the time required to scan and integrate the profile card information was minimal. The net result in this case was the ability to concentrate on monitoring the instruments and controlling the flight with less error.

The purpose of this discussion and example is to strongly point out that the selection of measures of task performance is critical. In this study, it can be seen that more than one conclusion could have been reached if only one or another of the performance measures had been used. Care must be taken in future studies to insure that all elements of task performance are adequately sampled, and interpretations and conclusions are based on not only individual measures but overall performance as well. This is critical not only from the standpoint of determining the magnitude and rate of skill degradation, but equally important for the selection or development of the most appropriate methods or combinations of methods which will prevent degradation. Most certainly, much of the conflict in the literature, concerning

the types of skills which degrade, when and by how much, and what retraining is required, was caused by the different measures of performance used to evaluate retention of task skills.

5. REFERENCES

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3. Slayton, D. K. Crew Training and Simulation. In Review of Lunar Landing Mission, Part 3: Lunar Landing through Earth Recovery. Science and Technology Advisory Committee, Houston Meeting, October 6 to 8, 1967, NASA Manned Spacecraft Center, Report S-N-8-R-031, 1967.

APPENDIX - SUBJECT TRAINING PACKAGE

Subject Training and Rehearsal Briefings

This appendix contains the materials initially presented to the test subjects at the beginning of their training and later used for rehearsal briefings. During the pretraining orientation the material was presented verbally. During the monthly retention interval rehearsal briefings and prior to the final test, the rehearsal group subjects read the briefing materials with only verbal clarification provided by the experimenter. The written continuous control and procedure task self-tests were completed with each rehearsal briefing followed by experimenter correction and clarification comments.

The introduction to both the subject training and retention interval rehearsal briefings were read to the subjects as follows:

Boeing is under contract to the NASA Manned Spacecraft Center at Houston to investigate the degradation of learned skills. The purpose of this study effort is to determine if certain learned skills degrade over time, and what techniques may be applied to counteract the effects of time-based skill degradation. In order to accomplish the required investigation we (are training) (have trained) a group of test subjects to perform simulated astronaut tasks. As one of the test subjects, you (will learn) (learned) two tasks associated with operating a simulated space vehicle for the ascent to orbit phase of the mission during your initial training. Upon completion of training, your performance (will be) (was) tested for later comparison with your performance at the end of (1) (2) (3) (4) (6) months.

The first task involves manual control of a simulated space vehicle from launch to orbit insertion. It is referred to as the "Continuous Control Task" in which basic flight instruments are monitored and control inputs made to "fly" the vehicle into the desired orbit.

The second task involves a simulated failure of a primary flight instrument and is referred to as the "Procedure Task." Meter readings are taken and systems actuated in order to investigate and alleviate (if possible) the emergency situation associated with attitude indicator failures.

The following instructions were read to the rehearsal group subjects only.

There are several groups of subjects who receive different types of retention training over different time intervals. Your group receives (monthly briefings) (a pre-test briefing) to refresh your memory of the tasks. This package contains briefing materials for both the continuous control and procedural tasks. Included with the training package are a series of photographs of the flight control display panel taken at 30 second intervals during the flight, corresponding to each of the checkpoints specified on the guidance reference card. Review these photographs, paying particular attention to the relationship between the instrument readings. During your review, try to anticipate the future flight progress and probable instrument readings expected at the next 30-second checkpoint.

At the end of each section, you are to complete a self-test which will assist you in judging how well you are retaining an understanding of these tasks. As a further learning aid, you are to correct your self-test as part of your (monthly) skill retention training.

D180-15081-1

FLIGHT CONTROL AND PROCEDURE

TRAINING PACKAGE

SIMULATED BOOST VEHICLE

CONTRACT NAS9-10962

Continuous Control Task

During the performance of the Continuous Control Task, a two-stage space vehicle will be manually controlled from the ground into an orbit at 273,000 feet.

The space vehicle weighs 3-1/2 million pounds at lift off with a total of 5 million pounds of thrust. The vehicle is oriented vertically on the launch pad (sitting on its tail) at blast-off and your primary control task is to manually provide the nominal rate of pitch. However, you are also required to minimize error deviations in the roll and yaw attitudes, which are primarily under automatic control.

Some of the basic vehicle attitude and movement definitions are illustrated in Figure A-1. The velocity vector defines the vehicle's flight path at any instant. The angle gamma is the flight path angle and is not displayed in the cockpit. The vehicle is illustrated in two positions: "A", aligned on the velocity vector and "B", in a pitched up attitude. The angle formed by the longitudinal axis of the vehicle and the velocity vector is called the angle of attack (α). The angle of attack is directly displayed by the cockpit instruments. The angle between the longitudinal axis of the vehicle and the local horizontal reference (horizon in this simulation) is the pitch angle. Pitch error, the error between the desired pitch angle and the actual vehicle pitch angle, is displayed on the Attitude Director Indicator (ADI).

Figure A-2 shows the cockpit display arrangement. The "Guidance Reference Card" is placed on the upper left hand side of the panel. This card displays programmed altitude, vertical velocity or altitude rate (\dot{h}), angle of attack (α), and velocity (v) and time (Figure A-3). The data is displayed for each 30 seconds. The one minute data points are underlined in red. The vehicle pitch (and roll and yaw) attitude must be controlled such that the altitude and altitude rate meters read the values indicated on the guidance card. Immediately below the guidance card are located the altimeter (h) and the vertical velocity (\dot{h}) meters.

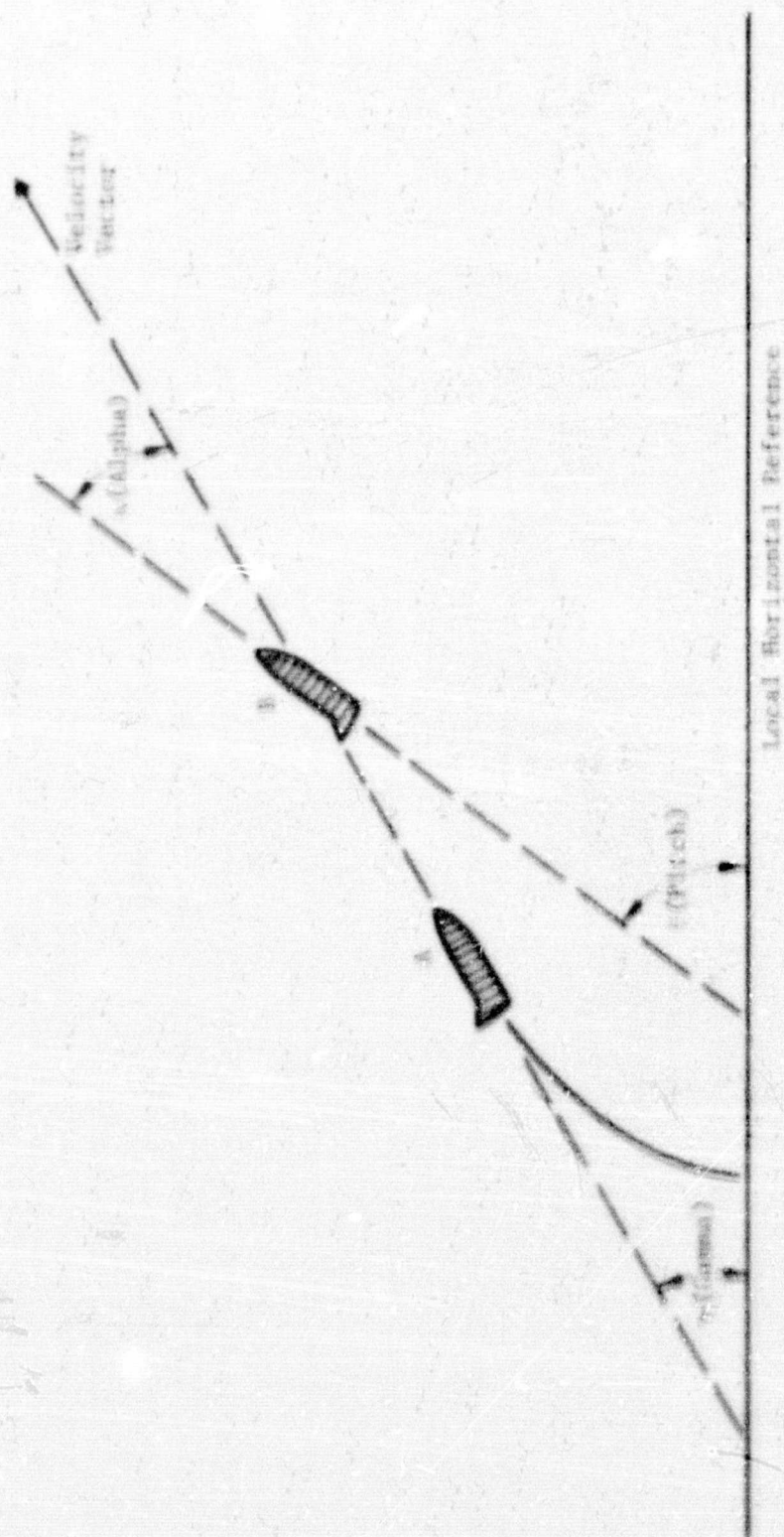


FIGURE A-1: FLIGHT CONTROL ANGLE DEFINITIONS

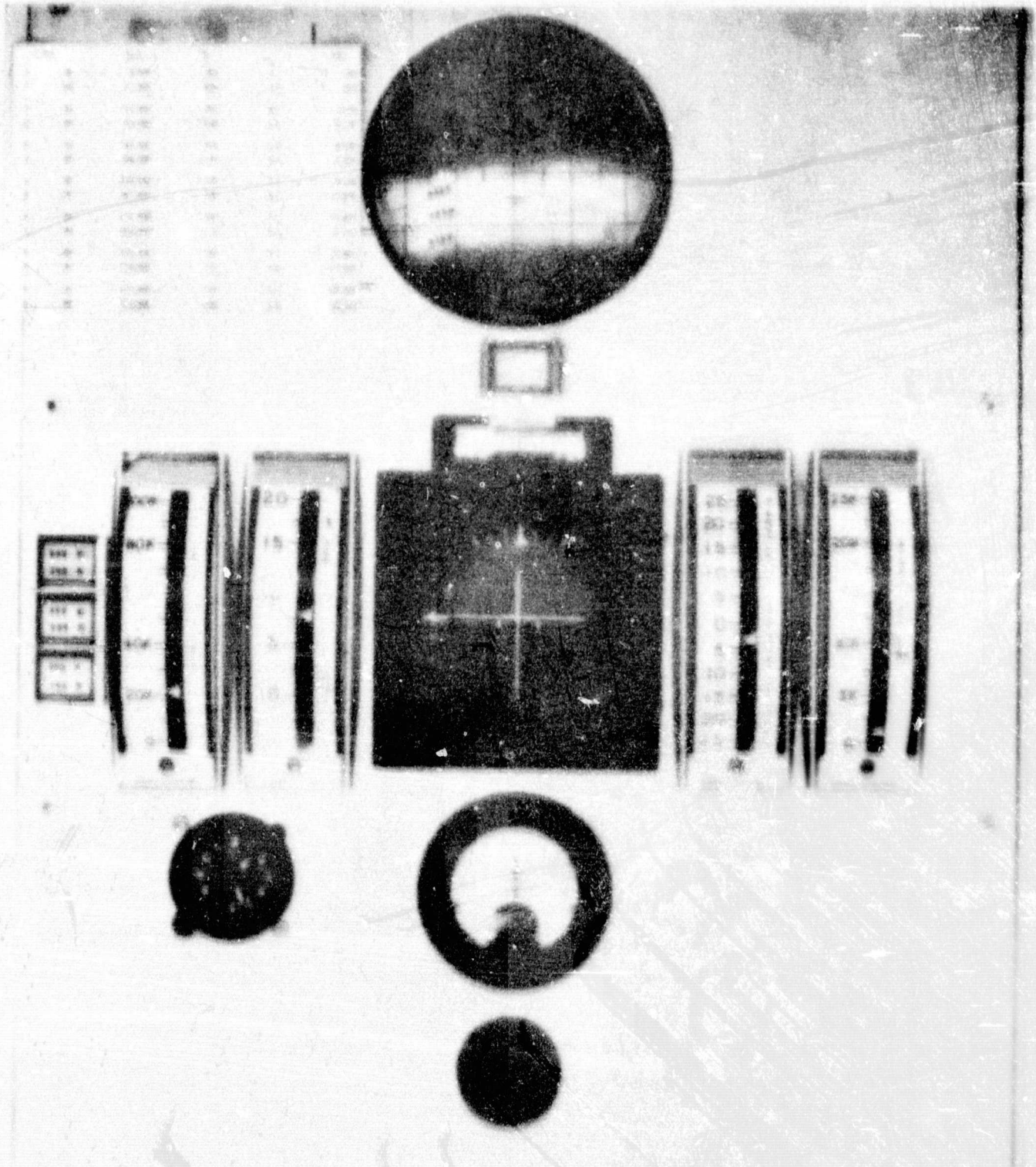


Figure A-7. Cockpit Display Panel for Flight Control Instruments

<u>TIME</u>		<u>ALT</u>	<u>h</u>	<u>a</u>	<u>VEL</u>
<u>0</u>	30	<u>4,800</u>	<u>350</u>	<u>0</u>	<u>500</u>
<u>1</u>	00	<u>21,000</u>	<u>800</u>	<u>-3.0</u>	<u>850</u>
<u>1</u>	30	<u>52,000</u>	<u>1,250</u>	<u>-4.0</u>	<u>1,500</u>
<u>2</u>	00	<u>93,000</u>	<u>1,500</u>	<u>2.5</u>	<u>2,700</u>
<u>2</u>	30	<u>142,000</u>	<u>1,650</u>	<u>2.5</u>	<u>4,500</u>
<u>3</u>	00	<u>189,000</u>	<u>1,550</u>	<u>-0.5</u>	<u>6,800</u>
<u>3</u>	30	<u>233,000</u>	<u>1,225</u>	<u>1.0</u>	<u>9,700</u>
<u>4</u>	00	<u>261,000</u>	<u>725</u>	<u>4.0</u>	<u>11,400</u>
<u>4</u>	30	<u>277,000</u>	<u>300</u>	<u>5.5</u>	<u>13,400</u>
<u>5</u>	00	<u>282,000</u>	<u>0</u>	<u>6.3</u>	<u>15,750</u>
<u>5</u>	30	<u>278,000</u>	<u>-190</u>	<u>6.0</u>	<u>18,450</u>
<u>6</u>	00	<u>273,000</u>	<u>-170</u>	<u>6.0</u>	<u>21,600</u>
<u>6</u>	30	<u>271,000</u>	<u>120</u>	<u>5.0</u>	<u>25,000</u>
<u>6</u>	<u>44</u>	<u>273,000</u>	<u>140</u>	<u>5.0</u>	<u>25,029</u>

Figure A-3. Guidance Reference Card - Data Required for Manual Flight Control

The "Altimeter" reads from 0 to 100,000 feet. At 100,000 feet the meter indicator returns to zero and the 100K light (located just to the left of meter) illuminates. The indicator then progresses upward, reading 110,00; 120,000, etc. to 200,000 feet. At 200,000 feet the 200K light illuminates and the indicator needle returns to zero and starts up into the 200,000 foot range. Each mark on the altimeter scale is equal to 2000 feet.

The "Vertical Velocity" meter has a range of minus 500 feet per second to plus 2000 feet per second. Each increment on the vertical velocity scale equals 50 feet per second. This is a very important parameter. If the reading is off by a single increment (50 ft/sec) at a 20 second check point and corrective action is not initiated, altitude at the next 30 second check point can be off by as much as 1500 feet.

The clock is positioned below the altimeter and vertical velocity meter. The button on the upper right side of the clock starts, stops and resets the clock with consecutive actuation of the button. There is a sweep second hand and a special minute hand (arrowhead shaped) that are used to check each of the time checkpoints during the flight duration of 6 minutes and 44 seconds.

The "Attitude Director Indicator" (ADI) is located in the center of the display panel just to the right of the vertical velocity meter. The ADI displays pitch error and roll attitude. When the pitch over rate is too slow, that is the actual pitch angle is higher than the nominal pitch angle, the wings on the ADI will rise above the horizon bar on the instrument. The required corrective action is to increase forward pressure on the side arm controller stick to "fly" the wings back down onto the horizon. The wings must always be flown back to the horizon. If the left wing is low, the control stick is moved to the right until the left wing rolls up to the horizon bar.

Directly above the ADI is the "Side Slip" indicator. The range of this indicator reads from 15° left to 15° right in one degree increments. This meter reads the angle of side slip from the velocity vector. If

the vehicle is yawed to the right (by rotating the control stick clockwise) the side slip meter will slowly indicate the right yaw and if the control stick is rotated counterclockwise, the meter will indicate yaw towards the left.

The "Compass Heading Error" indicator is located directly below the ADI. This meter has a range of 10 degrees left to 10 right in one degree increments. The deviation from the vehicle's programmed course is displayed on this indicator. Roll or yaw errors will add up to cause a compass heading error. In order to correct a compass heading error to the right, the vehicle is yawed to the left about 2 degrees for each degree of heading error and vice versa for compass heading errors to the left.

The "Altitude Error Display" is located at the top, center of the instrument panel. This display provides real time altitude error information. The diagonal lines and the numerals shown on the display are not used in this simulation. The dot on the scope will start on the center horizontal line at the point where the left vertical line intersects the center horizontal line. Nominally, the dot should travel from left to right across the scope on the center horizontal line as the mission is flown. If the vehicle flight path gets below the desired altitude, the dot will go below the center horizontal line and vice versa if the vehicle altitude gets high. The scale on the grid on the display is 4000 feet per horizontal line. Since there is up to 1000 feet of error inherent in the scope display, the instrument should be used as a secondary source of trend information and the altimeter should be used as the primary source of altitude information.

The "Angle of Attack" (α) meter is located directly to the right of the altitude director indicator (ADI). This meter has a scale that ranges from +25 to -25 degrees. Each increment on the scale equals one degree. This meter serves as a back up to the ADI and provides information that helps the pilot maintain the optimum "wing" position on the ADI. The angle of attack meter may also be used to provide some attitude reference if the vehicle attitude exceeds the pitch limits of the ADI.

The "Airspeed" or velocity meter is located directly to the right of the angle of attack meter. Direct control of velocity is not required in this simulation since thrust is automatically terminated when the optimum velocity is achieved. For this reason, velocity should not be monitored on either the profile card or the meter but instead, attention should be devoted to the primary instruments: the ADI, the vertical velocity (\dot{h}), and the altimeter (h).

The nominal profiles for the altitude, pitch, and vertical velocity are plotted against time and illustrated in Figure A-4. It can be seen that pitch starts at 90 degrees at time zero, then decreases smoothly to zero, goes slightly negative, then comes back up slightly above zero at the 6 minute, 44 second termination point. Altitude starts at zero, increases smoothly to a peak of 282,000 feet at 5 minutes then decreases to about 271,000 feet at 6 minutes, 30 seconds and finally increases to the nominal shut-off altitude of 273,000 feet at 6 minutes, 44 seconds. Vertical velocity (\dot{h}) starts at zero, rises rapidly to a peak of 1650 feet per second then descends smoothly to zero at 5 minutes and continues down to -200 feet per second at 5 minutes and 30 seconds. Vertical velocity then starts positive, going through zero at 6 minutes and 18 seconds, and reaching 140 feet per second at termination (6 minutes, 44 seconds). You are required to fly the profile as closely as possible such that you achieve the terminal altitude (273,000 feet) and vertical velocity (140 feet per second). Performance is measured on the basis of terminal altitude and vertical velocity error and on the total integrated pitch and altitude error.

After you are seated and have donned the headset and throat mike, trim the wings to zero pitch on the ADI. The operator at the outside console will request this trim. After the trim has been established, the ADI may not be retrimmed for the remainder of the training or test session without upsetting the data reference. Do not retrim after the wings have been zeroed. After the wings have been zeroed, the standby light at the left of the instrument panel will blink. You will then zero the clock and standby for the countdown. A "three, two, one - go" countdown

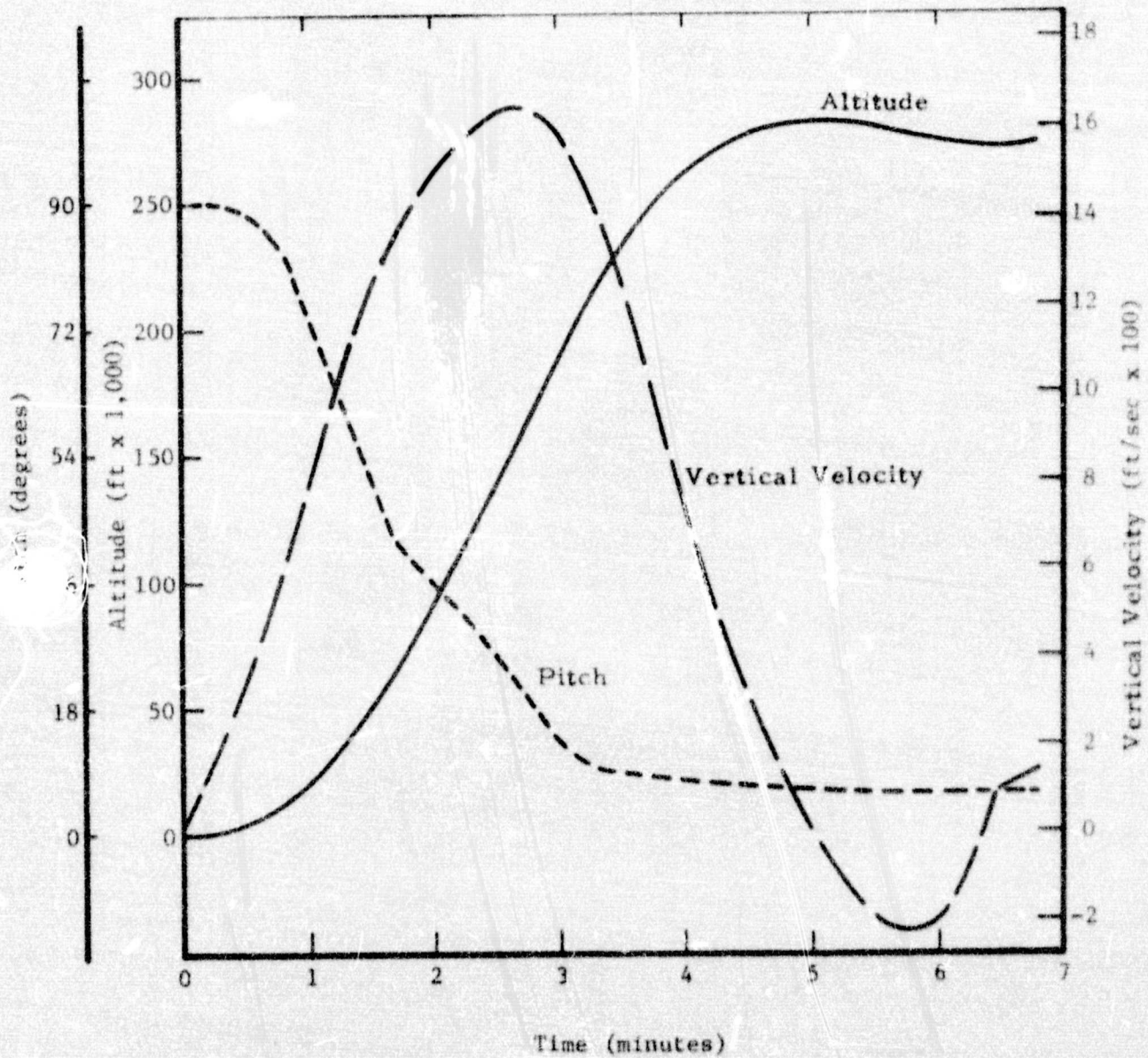


Figure A-4: NOMINAL FLIGHT PROFILES FOR ALTITUDE, PITCH, AND VERTICAL VELOCITY

will be heard over the headset. At "go", push the button that starts the clock and proceed to fly the profile.

In order to "fly" the profile in a manner that will meet the relatively stringent qualification criteria, it is necessary that the following piloting techniques be applied.

An eye scanning technique must be developed and applied as rapidly as possible. Specifically, all of the primary instruments must be scanned rapidly, and the secondary instruments must be used as cross check information. The attitude director indicator (ADI) is the instrument that should get about 70 percent of your attention. This instrument should be the center of the eye scan pattern, that is, you should glance at the ADI, then at the vertical velocity (\dot{h}), then back to the ADI, then to the altimeter (h), then back to the ADI, then to the clock, then back to the ADI, etc. As soon as a time check point passes, you should check the guidance card for the next check point altitude rate (\dot{h}) and altitude (h) values, then the scan should return to the three primary instruments, ADI, h and \dot{h} . An occasional glance at the altitude error scope (about once or twice per 30 seconds) will provide altitude trend information particularly if you have deviated widely (in excess of 2000 feet) from the optimum altitude profile. Also, an occasional glance at the angle of attack (α) meter (and the guidance card) will show the trend that the wings will take on the ADI, up or down depending upon whether α is travelling from -1 to -3° , (from 30 seconds to 1 minute) or from -5° to $+1^\circ$ (from 1 minute 30 seconds to 2 minutes). You normally will not have to glance at the yaw or heading error meters more than once each 30 seconds.

After the "go" signal is received, hold the wings zeroed on the horizon bar of the ADI. If this is done carefully and with very smooth, quick stick inputs, it is theoretically possible to fly a perfect profile. Normally, an error will occur in vertical velocity or altitude simply because of the inertias in the total man-machine system. As soon as an error is detected in vertical velocity or altitude a correction must be made to the wing position on the ADI. For example, if vertical velocity

appears to be 50 feet per second low at the 3 minute check point, "climb" back to the proper vertical velocity by holding the wings above the ADI horizon for a finite time period. For example, the wings should be held about 1/4 inch above the horizon for about 15 seconds to correct a 50 feet per second error in vertical velocity. This is an approximate correction and the values will vary with the size of the error and the time in the profile where the error occurs.

If an error is detected in altitude the same relationship on the ADI exists. Raise the wings above the horizon when the altitude is low, and put the wings below the horizon when the altitude gets too high. When correcting altitude it is generally best to identify the altitude error, then select a sing position that will give the desired change in vertical velocity at the next check point since the altitude is determined by the vertical velocity. For example, if the altitude appears to be 3000 feet high at 4 minutes, the wings should be set about 1/4 inch below the horizon bar for about 15 seconds in order to have the vertical velocity come in 50 feet per second low at the 4 minute 30 second check point. The vertical velocity must then be adjusted back upward in order to keep from overcorrecting the altitude.

The vehicle response time is significant. The effects of holding a correction may not be felt as long as 30 seconds later. This requires that the pilot remember where he was 30 seconds ago and predict where he will be 30 seconds in the future. The most common mistakes are the following:

1. Instrument fixation; failure to scan the instruments properly.
2. Over control; using wide stick movements when only small displacements are required.
3. Reference reversal on the ADI with respect to altitude and vertical velocity. (Putting the wings above the bar when you are already too high.)
4. Failure to consider the slow response time inherent in the vehicle system.
5. Misreading the altitude and vertical velocity meters.

Procedure Task

A possible failure in the attitude indicator system is the basis for the procedure task. Figure A-5 shows the Procedure Task cockpit display and control panel. While the space vehicle is being manually controlled (Continuous Control Task), an attitude indicator failure may be indicated. At this time, you may reach down on the right side of the cockpit, release the alligator clip and open the procedure task logic flow diagram (Figure A-6). It is emphasized that reference to the diagram is left to the option of the pilot. If you remember the procedure, you need not open the logic flow diagram. However, if you do want to look at the diagram, do not do so until you see the first "Attitude Indicator Failure" light.

As indicated on the logic flow diagram (Figure A-6), the first procedural step after the onset of the failure indicator light is to push the "Auto Control" button. This puts the vehicle on autopilot and permits you to give your full attention to the emergency checkout of the attitude indicator system. The next step in the sequence is to push the "System Check" button. It is important to note that the meter will only read while the button is held down. This action will cause the meter to indicate one of three readings. The meter will either indicate low (0.75), high (1.5) or an indeterminate, middle reading (1.0). A fourth possibility is that the meter will not read at all (no needle movement) indicating that the meter has failed.

If the meter reads high (1.5), it indicates the system is functioning properly. After a high (1.5) reading the next step is to push the "manual" button and fly the vehicle manually.

If the meter reads low (0.75) it indicates that a failure does exist in the system. After the low reading, the pilot pushes the "Alternate Attitude System" button. This button selects an alternate system which will now drive the ADI instrument. In order to ensure that the alternate system is operative and to ensure that the original failure is not common to the primary and alternate systems, you must recheck after

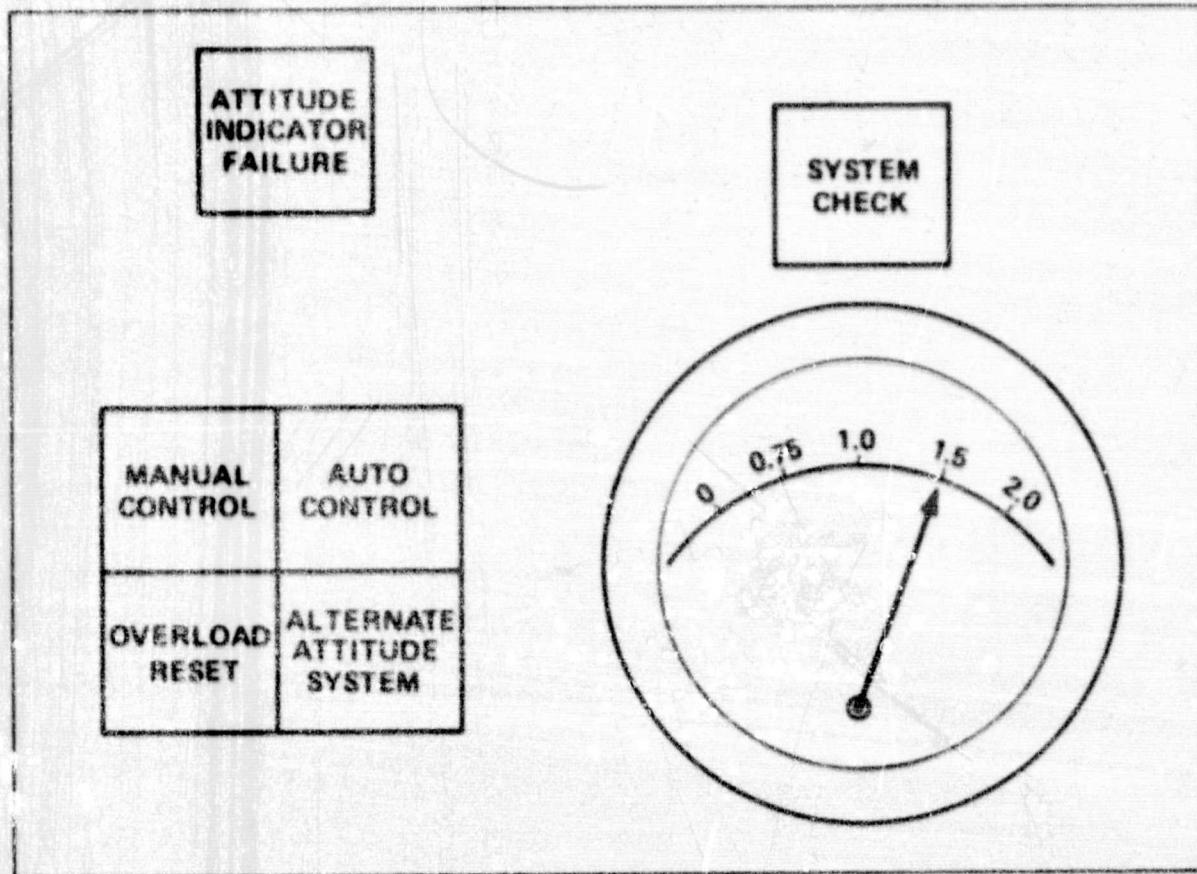


Figure A-5. Procedure Task Cockpit Display and Control Panel

selecting "Alternate Attitude System." When the "System Check" button is pushed, the reading will be one of the original four possibilities. If the meter reads low (0.75) after switching to "Alternate Attitude System" a failure exists in the alternate system and the proper procedure is to stop checking and continue the flight in "Auto Control."

Anytime the meter reads the middle reading (1.0), an indeterminate situation exists and you must push the "System Check" button again. If the meter reads two consecutive indeterminate readings (1.0), stop the check and continue the flight in "Auto Control."

If the meter fails to read at all (no needle movement), the "System Check" button should be released and pressed a second time. If two consecutive "No Read" indications result, stop the check and remain in "Auto Control."

Anytime that a button is pushed out of the proper sequence, the "Overload Reset" button will light. This indicates that the computer logic of the automatic inflight checkout system has been disrupted and the following procedure should be followed:

1. Push the "Overload Reset" button.
2. Push "Auto Control" button.
3. Repeat the "System Check" procedure.

There are fourteen different meter reading combinations. At the end of each combination the system will be returned to manual control, either by pilot action or by the simulation operator. The control status is indicated by the "Manual Control" or "Auto Control" button indicators. It is emphasized that when the "Manual Control" button is lighted, the vehicle must be controlled with manual inputs through the sidearm controller.

Error and time data are taken for each test combination so you should strive to complete the sequential checks as quickly and accurately as possible.

Rehearsal Briefing Self Tests

Upon completion of the continuous control task section, the subject was given the Flight Control Rehearsal Test. This test was jointly reviewed and corrected by the subject and experimenter prior to starting the review of the procedure task rehearsal material. The Attitude Indicator Failure Procedure Rehearsal Test was similarly administered and corrected.

FLIGHT CONTROL REHEARSAL TEST

1. When does \dot{H} reach its highest value? _____ What is that value? _____
2. When does \dot{H} first go to 0.0 ft/sec.? _____
3. What is the desired \dot{H} at 6 min.? _____ At 6 min. 30 sec.? _____
4. What is the maximum altitude attained during a normal ascent profile? _____ At what time does it occur? _____
5. What is the altitude at 5 min.? _____ At 6 min.? _____
At 6 min. 30 sec.? _____ At 6 min. 44 sec.? _____
6. When does alpha first begin to go negative? _____
7. Assuming that the flight has progressed on profile, what should alpha be:
At 5 min.? _____ At 6 min.? _____ At 6 min. 30 sec.? _____
8. Sketch the boost profile for altitude on the chart provided.
9. Sketch the flight display panel on the paper provided. Label the displays and indicate what are the primary and secondary (if applicable) displays for the flight parameters associated with vehicle altitude and attitude. Where possible, indicate the scale range for each instrument, i.e., -5° to $+40^{\circ}$.

ATTITUDE INDICATOR FAILURE PROCEDURE REHEARSAL TEST

1. What does an "Attitude Indicator Failure" light indicate? _____

2. What are the first 2 steps of the Attitude Indicator Failure procedure after the onset of the "Failure" light?
 1. _____
 2. _____
3. After actuation of "System Check" what is the correct response to the following meter readings?
 1. 1.0 _____
 2. No Reading _____
 3. 1.5 _____
4. What does an "Overload Reset" light indicate and what action is required?

5. What action is required after two successive indications of the following meter readings?
 1. 1.0 _____
 2. No Reading _____
 3. 1.5 _____
 4. 0.75 _____
6. What does a meter reading of 0.75 indicate, and what is the required action(s)?

7. On the paper provided, sketch the procedure task panel and indicate the pushbuttons and lights by name.